



IBM Systems - iSeries
Programming
Multithreaded applications

Version 5 Release 4





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Note

Before using this information and the product it supports, read the information in “Notices,” on page 71.

Eighth Edition (February 2006)

This edition applies to version 5, release 4, modification 0 of IBM i5/OS (product number 5722-SS1) and to all subsequent releases and modifications until otherwise indicated in new editions. This version does not run on all reduced instruction set computer (RISC) models nor does it run on CISC models.

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Contents

Multithreaded applications.	1	Synchronization techniques among threads	31
Printable PDF	1	One-time initialization and thread safety	46
Threads on i5/OS	1	Thread-specific data	48
Thread models.	1	Function calls that are not thread safe	51
Thread program models	2	Common multithreaded programming errors	53
Jobs and job resources	2	Language access and threads	56
Thread-private data and thread-specific data.	3	Threads considerations for Java language	56
Multithreaded program startup commands	4	Threads considerations for C language	56
Activation groups and threads	4	Threads considerations for C++ language	57
Communications considerations for multithreaded programming	5	Threads considerations for ILE COBOL and RPG language	57
Database considerations for multithreaded programming	5	Threads considerations for OPM language	57
Data management considerations for multithreaded programming.	10	Debugging and servicing of multithreaded jobs	58
File system considerations for multithreaded programming.	10	Commands that report thread-related data	58
Printer file considerations for multithreaded programming.	11	Flight recorders	59
i5/OS thread management	11	Options to view thread information	62
Thread attributes	11	Multithreaded job debugging	63
Start a thread.	14	Areas to test for multithreaded applications	64
End a thread	16	Performance considerations in multithreaded applications	65
Cancel a thread	18	Multithreaded server recommendations	65
Suspend a thread	21	Job and thread priorities	65
Resume a thread.	23	Contention among threads	66
Wait for a thread to end	23	Effects of storage pool sizes on threaded applications	66
Yield the processor to another thread.	26	Activity levels of storage pools	66
Thread safety.	27	Performance and threaded applications	66
Storage usage and threaded applications	27	Examples: Threads	67
Job-scoped resources and thread safety	28	Related information for multithreaded applications	68
API thread safety classifications	28	Code license and disclaimer information.	68
CL commands and thread safety	29	Appendix. Notices	71
Denied access functions and thread safety	30	Programming Interface Information	72
Exit points.	30	Trademarks	73
Multithreaded programming techniques.	31	Terms and conditions	73
Existing application evaluation	31		

Multithreaded applications

A *thread* is the path taken by a program while running, the steps performed, and the order in which the steps are performed.

The term thread is short for *thread of control*. A thread runs code from its starting location in an ordered, predefined sequence for a given set of inputs. You can use multiple threads to improve application performance by running different application tasks simultaneously.

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Threads on i5/OS

All programs have at least one thread, referred to as the *initial thread*. In a program with multiple threads, each thread runs its code independently of the other threads in the program.

A *process* is the container for the memory and resources of the program. On IBM®  iSeries™ systems, a job represents a process. Each process has at least one thread (task) in which the program runs its code. The first thread in a process is referred to as the initial thread. Some processes are capable of supporting additional threads, which are called secondary threads.

The concepts that are described here pertain to all programming languages. For details about how each language enables a concept, refer to the programmer's guide for that specific language.

Thread models

There are different models of thread usage: user threads and kernel threads.

In the user threads model, all program threads share the same process thread. In the user thread model, the thread application programming interfaces (APIs) enforce the scheduling policy and decide when a new thread runs. The scheduling policy allows only one thread to be actively running in the process at a time. The operating system kernel is only aware of a single task in the process.

In the kernel threads model, kernel threads are separate tasks that are associated with a process. The kernel thread model uses a preemptive scheduling policy in which the operating system decides which

thread is eligible to share the processor. In a kernel thread model, there is a one-to-one mapping between program threads and process threads. i5/OS™ supports a kernel thread model.

Some platforms support a combination of these two thread models commonly referred to as an MxN thread model. Each process has M user threads that share N kernel threads. The user threads are scheduled on top of the kernel threads. The system allocates resources only to the more "expensive" kernel threads.

Thread program models

There are different models for creating multithread programs.

One of the key differences between i5/OS and other platforms is the ability of i5/OS to support a call-return program model. On other platforms, if one program wants to call another, it must start a second process to run the second program, or replace the first program with the second. Starting another process to call a program is expensive in terms of startup time and system resources. To avoid this expense, programmers group commonly used functions into dynamically linked libraries (DLLs). Whenever a program needs a service that a DLL provides, the program loads the DLL and calls the function that provides the needed service.

Although the i5/OS call-return program model is supported for multithreaded programs, you are strongly encouraged to use service programs or DLLs that run in the caller's activation group. If you perform ports of multithreaded programs from other platforms, you will naturally employ service programs in their port.

Although it is not a requirement, all programs used in a multithreaded application should be Integrated Language Environment® (ILE) programs. The use of the original program model (OPM) in multithreaded programs requires special considerations. You must evaluate the thread safety of existing ILE or OPM programs if multithreaded programs call them.

Related reference

"Threads considerations for OPM language" on page 57
Original program model (OPM) programs are not threadsafe.

Jobs and job resources

A *job* is a container for storage and other resources. A job cannot run by itself.

Every job has two basic kinds of storage associated with it.

Data: Data is where all of the program variables are stored. It is broken down into storage for global and static variables (static), storage for dynamically allocated storage (heap), and storage for variables that are local to the function (automatic). The storage for program variables is allocated from the activation group into which the program was activated. Static and heap storage are accessible to all threads that are running in the activation group. The automatic storage and local program variables are local to the thread.

Stack: The stack contains data about the program or procedure call flow in a thread. The stack, along with automatic storage, is allocated for each thread created. While in use by a thread, the stack and automatic storage are considered to be thread resources. When the thread ends, these resources return to the process for subsequent use by another thread.

Job resources are resources that are accessible by all threads within the job. These resources are as follows:

- Coded character set identifier (CCSID)
- Locales
- Environment variables

- File descriptors
- Files that are opened with a job scope
- Signal action vector
- Signal timers
- The current working directory

All threads running in an activation group can share activation group resources, such as static and heap storage. When a thread changes a job resource, the new value is immediately visible to all threads. For example, changing the signal handling action in one thread effectively changes the signal handling action in all threads.

Thread-private data and thread-specific data

Threads cannot share certain resources. Data that threads cannot share between themselves are called thread-private data.

The operating system defines this thread-private data. i5/OS defines the following resources as thread-private data:

- Thread identifier:
The unique integral number that can be used to identify the thread.
- Priority:
i5/OS allows specification of a thread priority, which determines the relative importance of one thread to other threads in the job. The thread priority is defined to be a delta value to the job's priority. i5/OS adds the thread's priority to the job's priority. It can never exceed the job's priority. If you adjust the job's priority, the thread's priority is adjusted relative to the new job priority. The default thread priority value is zero. This results in a thread that has the same priority as the job.
- Security information:
Security information, including user and group profiles, is maintained on a per thread basis. When a thread creates a new thread, the new thread inherits the security information from the thread that created it.
- Library list:
Library list information, including user and group profiles, is maintained on a per thread basis. When a thread create a new thread, the new thread inherits the library list information from the thread that created it.
- Signal blocking mask:
The signal blocking mask identifies the set of asynchronous signals to be blocked from delivery to the thread. When a thread creates a new thread, the new thread inherits the signal blocking mask of the thread that created it.
- Call stack:
The call stack contains data about the program flow or procedure call flow in a thread. The stack, along with automatic storage, is allocated for each thread created.
- Automatic storage:
Automatic storage is for variables that are local to the function.
- errno variable:
The program variable that is used to return the result of a C or POSIX system call. errno is a function call that returns the most recent result for a function call in the thread.

Threads can have their own view of data items called thread-specific data. Thread-specific data is different from thread-private data. The threads implementation defines the thread-private data, while the application defines the thread-specific data. Threads do not share thread-specific storage (it is specific to a

thread), but all functions within that thread can access it. Typically, a key indexes thread-specific storage. The key is a global value that is visible to all threads. It is used to retrieve the thread-specific value of the storage associated with that key.

Multithreaded program startup commands

To call a multithreaded Integrated Language Environment (ILE) program, the job in which the program is called must be capable of supporting multiple threads (multithread-capable). Multithreaded Java™ programs can be called in most jobs (some system jobs restrict the types of programs that can be called).

In the i5/OS kernel threads support, only a subset of the supported job types can create threads. Interactive and communication jobs do not provide multithread-capable support.

The parameter **Allow Multithread (ALWMLTTHD)**, which is located in the Create Job Description (CRTJOBDD) and Change Job Description (CHGJOBDD) commands, controls whether the job supports multiple threads. i5/OS examines all job types except communications jobs and interactive jobs for the **ALWMLTTHD** parameter. The Add Prestart Job Entry (ADDPJE) and Change Prestart Job Entry (CHGPJE) subsystem description job entry commands use the **ALWMLTTHD** setting to control whether jobs started through the entry are capable of supporting multiple threads.

The spawn() API, Spawn Process, supports a new flag field in the inheritance structure that controls whether the child process can support multiple threads. This flag field, SPAWN_SETTHREAD_NP, is a non-standard, i5/OS platform-specific extension to the inheritance structure. The spawn() API is the only programming method that can start a batch immediate or prestart job that is capable of supporting multiple threads. You can write a SPAWN command, similar to the CALL command, to simplify calling multithreaded programs. An example SPAWN command is available for your use and modification as part of i5/OS option 7, the i5/OS Example Tools Library, QUSRTOOLS.

Activation groups and threads

All programs and service programs are activated within a substructure of a job that is called an activation group. This substructure contains the resources necessary to run the programs, including static and heap storage, and temporary data management resources.

In a job capable of multithreaded operation, two or more threads can share an activation group. A thread can run programs that were activated in different activation groups. The system does not keep a list of threads that run in an activation group or a list of activation groups in a thread. Ending an activation group while other threads are active in it can produce unpredictable results including abnormal end of the process. To avoid these problems, any action that ends an activation group in a secondary thread causes the system to end the job in an orderly fashion. In other words, the system ends all threads in the job, calls exit routines and C++ destructors in the initial thread, and finally closes the files.

When working with activation groups, consider the following items:

- Return from activation groups:

Programs created with **ACTGRP(*NEW)** get a new activation group every time it is called. When the program returns, the new activation group ends. In jobs capable of multithreaded operation, returning from programs that were created with **ACTGRP(*NEW)** will end the job.

Both default and named activation groups are persistent. The Default activation group is created when a job starts and is destroyed only when the job ends. Named activation groups are created when they are first needed in a job. A normal return from the named activation group leaves the activation group in last-used state, but does not delete the activation group. Hence, in a job capable of multithreaded operations, a normal return from the default or named activation group does not cause the job to end.

Using exit() or abort() in any activation group in a secondary thread always ends the job.

- Unhandled exceptions:

If an exception has not been handled by the time it has percolated to the control boundary and the control boundary is a program entry procedure (PEP or main entry point), the multithread-capable job is ended.

- Reclaim activation group (RCLACTGRP):

Jobs capable of multithreaded operation allow this command to be called only in the initial thread on the job. If secondary user threads are present in the job, this command sends a CPF180B escape message to the caller of the command.

Related concepts

“Thread safety” on page 27

A function is threadsafe if you can start it simultaneously in multiple threads within the same process.

A function is threadsafe if and only if all the functions it calls are also threadsafe.

Communications considerations for multithreaded programming

The only threadsafe communications protocol supported on i5/OS is sockets.

The use of sockets is subject to the following restrictions:

- Socket APIs:

The majority of the sockets interfaces are threadsafe, but most of the network routines are not due to the use of static storage. These routines have been replaced with threadsafe *_r* counterparts. For example, you should replace calls to `gethostbyaddr()` with `gethostbyaddr_r()`. The *_r* routines are compatible with the UNIX[®] definition. All *_r* functions reside in the existing service program QSOSRV2.

- AnyNet[®] using sockets:

AnyNet using sockets is considered threadsafe and is supported in multithread programs. However, this support has not undergone any formal testing.

Database considerations for multithreaded programming

You should consider these items when using databases in multithreaded programs.

- Data definition language (DDL):

Many of the database configuration, administration, and setup type interfaces are threadsafe. Database operations that are threadsafe include: Create File, Add Member, Delete File, and Remove Member. Refer to CL Reference or use the Display Command (DSPCMD) command to determine if a command is threadsafe. The online help information for that command lists any necessary conditions for threadsafety that apply to a command.

- Database record I/O:

The database protects the I/O operations for the duration of the operation (read, update, insert, or delete). When you share an open instance of a file among threads, you must serialize access to the I/O feedback areas and I/O buffers to see valid information in these areas. These areas are under application control, and the database cannot protect them after the database operation has been completed.

An example is a read operation. If thread 1 is in the process of a read operation and thread 2 performs any I/O operation against the same open instance, thread 2 waits until thread 1 has completed the reading. The result of the read operation in thread 1 is placed in the I/O buffer. When control returns to thread 1, thread 2 begins its I/O operation. Without serialization, thread 2 can change the information in the I/O buffer before thread 1 can view the result.

If threads do not share an open instance of a file, no serialization is required.

- Distributed files:

Access to distributed database files used with the DB2[®] Multisystem and access to distributed data management (DDM) files of type *SNA are not threadsafe. Multithreaded jobs deny access to database files of these types. These file types cannot be made threadsafe because intersystem communications function (ICF) files and the entire Systems Network Architecture (SNA) layer are not threadsafe. If an

attempt is made to open one of these file types, a CPF4380 message (Open attributes not valid in a multithreaded process) is sent to the function attempting to open the file.

- **Trigger programs:**

You can fire trigger programs in a multithreaded job. The same threadsafety restrictions apply to trigger programs as to any other code that runs in a multithreaded job. Parameters on the Add Physical File Trigger (ADDPFTRG) command allow for specification of the trigger's threadsafety status and the action to take if the trigger is fired in a multithreaded job.

- **Format selector programs:**

For logical files with multiple formats, the use of format selector programs is not threadsafe. You should not use format selector programs in a multithreaded job.

- **Stored procedures:**

DB2 Structured Query Language (SQL) stored-procedure support provides a way for an SQL application to define and call an external program through SQL statements. Stored procedures can be called in a multithreaded job. The same thread safety restrictions apply to stored procedures as to any other code that runs in a multithreaded job. Unlike trigger programs, there is no way to specify the stored procedure's thread safety status and the action to take if the stored procedure is called in a multithreaded job.

- **SQL statements:**

The use of DDL SQL statements might not be threadsafe. Data manipulation language (DML) statements are threadsafe.

- **Server mode for SQL:**

Using the server mode for SQL is the preferred method for accessing databases with multithreaded applications. A job can use the server mode for SQL in order to manage multiple database connections and transactions. When the application is using server mode for SQL, i5/OS uses the connections in the job as a more encapsulated representation of the current database context than previously permitted in i5/OS. It allows for connections to a database by multiple users, multiple connections to a database by the same or different users, and the existence of multiple, independent transactions by connections to a database.

Use one of the following mechanisms to activate server mode for SQL before data access occurs in the application:

- Use the Open Database Connectivity (ODBC) API, `SQLSetEnvAttr()` and set the `SQL_ATTR_SERVER_MODE` attribute to `SQL_TRUE` before doing any data access.
- Use the Change Job API, `QWTCGJJB()` and set the 'Server mode for Structured Query Language' key before doing any data access.
- Use Java Database Connectivity (JDBC) to access the database. JDBC automatically uses server mode to preserve required semantics of JDBC.

Server mode for SQL behavior:

- For embedded SQL, each thread in a job is a separate transaction that can be committed or rolled back, even if there are multiple connections within that thread.
- For ODBC, call level interface (CLI), and JDBC, each connection handle represents a stand-alone connection to the database and can be committed and used as a separate entity.

The CLI for SQL is threadsafe.

- **Commitable transactions:**

The introduction of threads does not change the scope of commitable transactions. You can scope commitable units of work to either a job-level commitment definition or an activation group-level commitment definition. A thread commit or rollback operation commits or rolls-back all operations done under the commitment definition. If you want an application where each thread (or group of threads) has a separate commitable transaction, you must either use server mode for SQL or manage these transactions with separate activation groups.

Related reference

“Database record I/O and thread safety” on page 55

You can use the I/O feedback area of a database file to communicate results of I/O operations to the record I/O user. A typical application might have problems with thread safety because of the nature of the feedback area.

“Example: Work with local SQL databases in multithreaded Pthread programs”

This example shows how to work with local SQL databases in multithreaded Pthread programs.

“Exit points” on page 30

The i5/OS registration facility allows you to define exit points for functions in an application and to register programs that run at those exit points.

“Commit operations in multithreaded programs” on page 55

Database transactions in i5/OS are scoped to the job or the activation group.

Related information

CL Reference

Threads topic in SQL Reference

SQL Call Level Interface (ODBC)

Example: Work with local SQL databases in multithreaded Pthread programs

This example shows how to work with local SQL databases in multithreaded Pthread programs.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/* ***** */
/* Testcase: SQLEXAMPLE */
/* */
/* Function: */
/* Demonstrate how Embedded SQL can be used within a */
/* threaded ILE C program. This program creates and */
/* populates an SQL Table with data. Then, threads are */
/* created which each open a cursor and read all the */
/* data from the table. A semaphore is used to show */
/* how threads execution can be controlled. */
/* */
/* To compile program: */
/* CRTSQLCI OBJ(QGPL/SQLEXAMPLE) SRCFILE(QGPL/QCSRC) */
/* COMMIT(*NONE) RDB(*NONE) OBJTYPE(*MODULE) */
/* OUTPUT(*PRINT) DBGVIEW(*SOURCE) */
/* */
/* To bind program: */
/* CRTPGM PGM(QGPL/SQLEXAMPLE) */
/* MODULE(QGPL/SQLEXAMPLE) ACTGRP(*CALLER) */
/* */
/* To invoke program: */
/* SPAWN QGPL/SQLEXAMPLE */
/* */
/* ***** */
#define _MULTI_THREADED
#include <pthread.h>
#include <sys/sem.h>
#include <sys/types.h>
#include <fcntl.h>
#include <stdio.h>
#include <unistd.h>

static int semid;
static struct sembuf op_try1[1] = {0,0,0};
#define MAXTHREADS 2

void *threadrtn(void *parm);

int main(int argc, char **argv)
```

```

{
  int          rc;
  int          *status;
  pthread_t    thids[MAXTHREADS];
  EXEC SQL BEGIN DECLARE SECTION;
  int          i, j;
  char         insert[200];
  EXEC SQL END   DECLARE SECTION;

  EXEC SQL INCLUDE SQLCA;
  EXEC SQL INCLUDE SQLDA;

  /* create a new semaphore */
  semid=semget(IPC_PRIVATE,1,S_IRUSR|S_IWUSR);

  printf("\nsemaphore created\n");
  rc=semctl(semid, 0, SETVAL, 1);

  printf("semaphore initied\n");
  EXEC SQL WHENEVER SQLERROR CONTINUE;
  EXEC SQL CREATE TABLE QGPL/SQLEXMP (COL1 INT,COL2 INT);

  printf("SQL table created\n");
  EXEC SQL WHENEVER SQLERROR GO TO :mainerror;

  for (i=1,j=100;i<10;i++,j++) {
    (void) sprintf(insert, "INSERT INTO QGPL/SQLEXMP \
      VALUES(%d, %d)", i, j);
    EXEC SQL EXECUTE IMMEDIATE :insert;
  }

  printf("Table primed with data\n");
  for (i=0;i<MAXTHREADS;i++) {
    pthread_create(&thids[i], NULL, threadrtn, NULL);
  }
  printf("Threads created\n");

  rc=semctl(semid, 0, SETVAL, 0);

  printf("Threads turned loose\n");
  for (i=0;i<MAXTHREADS;i++) {
    pthread_join(thids[i], &status);
  }

  printf("Threads joined\n");
  return;

mainerror:
  printf("ERROR: sqlcode = %d sqlstate = %d\n", SQLCODE, SQLSTATE);
}

/*****
/* This thread will do the following:
/* - Declare a cursor for the example table
/* - Block on a semaphore until initial thread
/*   is ready for us to run
/* - Open the cursor
/* - Fetch data one row at a time in a loop until
/*   End of File is reached or an error occurs
/* - Close the cursor and return
*****/
void *threadrtn(void *parm)
{
  EXEC SQL INCLUDE SQLCA;
  EXEC SQL INCLUDE SQLDA;

  EXEC SQL BEGIN DECLARE SECTION;

```

```

long HV1, HV2;
EXEC SQL END DECLARE SECTION;

EXEC SQL WHENEVER SQLERROR GO TO :thderror;
EXEC SQL WHENEVER NOT FOUND GO TO :thdeof;

EXEC SQL DECLARE C1 CURSOR FOR SELECT * FROM QGPL/SQLEXMP;

/* block on semaphore */
semop(semid,&op_try1[0],1);

EXEC SQL OPEN C1;
printf("thid:%.8x %.8x: cursor open\n",pthread_getthreadid_np());

/* Loop until End of File (EOF) */
for (;;) {
    EXEC SQL FETCH C1 INTO :HV1, :HV2;
    printf("thid:%.8x %.8x: fetch done... COL1=%d COL2=%d\n",
        pthread_getthreadid_np(), HV1, HV2);
}

thderror:
printf("thid:%.8x %.8x: sqlcode = %d sqlstate = %d\n",
    pthread_getthreadid_np(), SQLCODE, SQLSTATE);
EXEC SQL CLOSE C1;
return;

thdeof:
printf("thid:%.8x %.8x: Done!\n",
    pthread_getthreadid_np());
return;
}

```

```

Testcase output:
semaphore created
semaphore initied
SQL table created
Table primed with data
Threads created
Threads turned loose
thid:00000000 00000022: cursor open
thid:00000000 00000023: cursor open
thid:00000000 00000023: fetch done... COL1=1 COL2=100
thid:00000000 00000022: fetch done... COL1=1 COL2=100
thid:00000000 00000023: fetch done... COL1=2 COL2=101
thid:00000000 00000022: fetch done... COL1=2 COL2=101
thid:00000000 00000023: fetch done... COL1=3 COL2=102
thid:00000000 00000022: fetch done... COL1=3 COL2=102
thid:00000000 00000023: fetch done... COL1=4 COL2=103
thid:00000000 00000022: fetch done... COL1=4 COL2=103
thid:00000000 00000023: fetch done... COL1=5 COL2=104
thid:00000000 00000022: fetch done... COL1=5 COL2=104
thid:00000000 00000023: fetch done... COL1=6 COL2=105
thid:00000000 00000022: fetch done... COL1=6 COL2=105
thid:00000000 00000023: fetch done... COL1=7 COL2=106
thid:00000000 00000022: fetch done... COL1=7 COL2=106
thid:00000000 00000023: fetch done... COL1=8 COL2=107
thid:00000000 00000022: fetch done... COL1=8 COL2=107
thid:00000000 00000023: fetch done... COL1=9 COL2=108
thid:00000000 00000022: fetch done... COL1=9 COL2=108
thid:00000000 00000023: Done!
thid:00000000 00000022: Done!
Threads joined

```

Related reference

“Database considerations for multithreaded programming” on page 5
You should consider these items when using databases in multithreaded programs.

Data management considerations for multithreaded programming

You should consider several topics when managing data in a multithreaded program.

- File open operations:

Only integrated file system stream files, printer files, distributed data management (DDM) files of type *IP, and local database files can be opened in a multithread-capable job. Attempts to open *FILE objects other than print files, type *IP DDM files, or local database files cause a CPF4380 escape message to be sent to the function that opens the file. The CPF4380 escape message signals that open attributes are not valid in a multithreaded process. Local database files include physical and logical files. Loosely coupled parallel (LCP) files are not local and send the CPF4380 escape message when a function tries to open the file. Local database files also do not include save files (*SAVF), which are device files, or other communications files. You cannot open a printer file by specifying SPOOL(*NO). If you specify SPOOL(*NO) when trying to open the print file, the CPF4380 escape message is sent to the function that tried to open the print file.

Multithread-capable jobs allow shared opens. However, an open data path (ODP) cannot be shared between threads. If a file is opened SHARE(*YES) and OPNSCOPE(*ACTGRPDFN) is specified, any subsequent shared open within the same thread that is running in the same activation group can share the ODP. If a file is opened SHARE(*YES) with OPNSCOPE(*JOB) specified, any subsequent shared open of the file within the same thread can share the ODP.

- File overrides:

Multithreaded applications can only issue overrides in their initial thread. Any attempt to issue an override in a secondary thread returns the CPF180C escape message. Only overrides with job-level and activation group-level scope affect secondary threads; overrides of call-level scope are not visible. Overrides of all scope levels can affect initial threads. You can use three different types of file override commands: Override with Database File (OVRDBF), Override with Printer File (OVRPRTF), and Override with Message File (OVRMSGF).

You can delete overrides in the initial thread, but not in secondary threads, by calling the Delete Override (DLTOVR) command. DLTOVR returns the CPF180C escape message if thrown against a secondary thread.

- Reclaim resources commands:

None of the commands that reclaim resources are threadsafe because the i5/OS operating system does not track resources. The operating system cannot identify which resources are in use by which threads. You cannot call the Reclaim Resources (RCLRSC) and Reclaim Activation Group (RCLACTGRP) commands in secondary threads. RCLRSC and RCLACTGRP can be called in the initial thread of a multithread-capable job (**ALWMLTTHD(*YES)**) if secondary user threads are not present. If secondary user threads are present in the job, these commands send a CPF180B escape message to the caller of the command.

Related reference

“Printer file considerations for multithreaded programming” on page 11
Only printer files opened with SPOOL(*YES) are allowed in a job that is capable of multithread operations.

File system considerations for multithreaded programming

You should consider several topics when working with file systems in multithreaded programs.

- Threadsafe file systems:

The Root, QOpenSys, User-Defined (UDFS), QNTC, QSYS.LIB, QOPT, and QLANSrv file systems are threadsafe and do not have any restrictions. The QDLS, NFS, QFileSvr.400, and QNetWare file systems are not threadsafe. If you try to use an integrated file system application programming interface (API) or command on a file or file descriptor that represents an object in a file system that is not threadsafe, it fails with ENOTSAFE. This failure occurs only when multiple threads are in a job.

An attempt to spawn a program from a job that has multiple threads fails with ENOTSAFE if you inherit the current working directory or open file descriptors that represent files in a file system that is not threadsafe.

- Integrated file system APIs:

All of the integrated file system APIs are threadsafe when directed to an object that resides in a threadsafe file system. If you do not know the file system where an object resides, you can query the path to see if the threadsafe integrated file system interfaces can safely access it. You can use the `pathconf()`, `fpathconf()`, `statvfs()`, and `fstatvfs()` APIs to determine whether a path or file descriptor refers to an object in one of the threadsafe file systems.

Printer file considerations for multithreaded programming

Only printer files opened with `SPOOL(*YES)` are allowed in a job that is capable of multithread operations.

Unspooled opens of printer files fail with a CPF4380 (Open attributes not valid in a multithreaded process) escape message sent to the function that requested the open.

Most SNA character string (SCS), Intelligent Printer Data Stream™ (IPDS™), Advanced Function Printing™ data stream (AFPDS), LINE, and USERASCII write operations are threadsafe. Write operations that are not threadsafe include those that use SCS graphics, those that the System/36™ Environment uses, those generated by the User Interface Manager (UIM), and those that use System/36 PRPQ subroutines. Page and line counts might be inaccurate because those counters cannot be atomically updated.

Related reference

“Data management considerations for multithreaded programming” on page 10
You should consider several topics when managing data in a multithreaded program.

i5/OS thread management

The concepts described here pertain to all programming languages.

For details about how each language enables a concept, refer to the programmer’s guide for that specific language.

Related information

Pthread APIs

Thread attributes

Thread attributes are thread characteristics that affect the behavior of the thread. Different attributes are available depending on the programming language and API set that you are using.

Methods for using an attribute and its effect on the thread depend on how the programming language and API set externalize the thread attribute to your application. You can set the thread attributes at the time you start a thread or change them after the thread is actively running.

Some common thread attributes and their effects are as follows:

- Priority:
The priority attribute affects the amount of processing time that the system gives the thread before letting another thread or process interrupt it.
- Stack size:
The stack size attribute affects the number of functions that a thread can call before the thread fails due to insufficient stack space.
- Name:

The name attribute affects the ability to debug or track the actions of a thread through your application.

- Thread group:

The thread group attribute affects the ability to easily manage more than one thread at a time.

- Detach state:

The detach state attribute affects how you reclaim or leave active resources associated with a thread when a thread ends.

- Scheduling policy:

The scheduling policy attribute affects how the threads are scheduled within the system or within the application. This relates to thread priority.

- Inherit scheduling:

The inherit scheduling attribute affects how the priority of the thread is determined by the system.

Example: Set a thread attribute in a Pthread program

This example shows how to set the "detach state" thread attribute in a Pthread program.

Note: By using the code examples, you agree to the terms of the "Code license and disclaimer information" on page 68.

```
/*
Filename: ATEST10.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST10
Create a default thread attributes object
Set the detach state thread attribute
Create a thread using the new attributes
Destroy thread attributes object
Join now fails because the detach state attribute was changed
Entered the thread
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

void *theThread(void *parm)
{
    printf("Entered the thread\n");
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_attr_t    attr;
    pthread_t         thread;
    int               rc=0;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Create a default thread attributes object\n");
    rc = pthread_attr_init(&attr);
    checkResults("pthread_attr_init()\n", rc);
```

```

printf("Set the detach state thread attribute\n");
rc = pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_DETACHED);
checkResults("pthread_attr_setdetachstate()\n", rc);

printf("Create a thread using the new attributes\n");
rc = pthread_create(&thread, &attr, theThread, NULL);
checkResults("pthread_create()\n", rc);

printf("Destroy thread attributes object\n");
rc = pthread_attr_destroy(&attr);
checkResults("pthread_attr_destroy()\n", rc);

printf("Join now fails because the detach state attribute was changed\n");
rc = pthread_join(thread, NULL);
if (rc==0) {
    printf("Unexpected results from pthread_join()\n");
    exit(1);
}
sleep(2);

printf("Main completed\n");
return 0;
}

```

Example: Set a thread attribute in Java

This example shows how to set the "name" thread attribute in a Java program.

Note: By using the code examples, you agree to the terms of the "Code license and disclaimer information" on page 68.

```

/*
FileName: ATEST10.java

The output of this example is as follows:
Entered the testcase
Create a thread
Set some thread attributes
Start the thread
Wait for the thread to complete
Entered the thread: "theThread"
Testcase completed
*/

import java.lang.*;

public class ATEST10 {

    static class theThread extends Thread {
        public void run() {
            System.out.print("Entered the thread: \"" + getName() +
                "\"\n");
        }
    }

    public static void main(String argv[]) {
        System.out.print("Entered the testcase\n");

        System.out.print("Create a thread\n");
        theThread t = new theThread();

        System.out.print("Set some thread attributes\n");
        t.setName("theThread");

        System.out.print("Start the thread\n");
        t.start();

        System.out.print("Wait for the thread to complete\n");
    }
}

```

```

    try {
        t.join();
    }
    catch (InterruptedException e) {
        System.out.print("Join interrupted\n");
    }

    System.out.print("Testcase completed\nj");
    System.exit(0);
}
}

```

Start a thread

When your application creates a new thread, the system initializes a thread object, control structures, and runtime support. These allow the new thread to use language constructs and system services safely.

In addition, you might need to initialize the application data and parameters the new thread uses before starting the new thread.

As you create each thread, the system assigns it a unique thread identifier. The thread identifier is an integer value that you can use when you debug, trace, or perform other administrative activities on the thread. You typically do not use this thread identifier to directly manipulate the thread.

Most threads API sets also return a thread object or handle that represents the newly created thread. You can use this thread object to manipulate the new thread or as a synchronization object to wait for the thread to finish its processing.

Example: Start a thread in a Pthread program

This example shows how to start and pass parameters to a thread in a Pthread program.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
Filename: ATEST11.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST11
Create/start a thread with parameters
Wait for the thread to complete
Thread ID 0000000c, Parameters: 42 is the answer to "Life, the Universe and Everything"
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}
typedef struct {
    int    threadParm1;
    char   threadParm2[124];
} threadParm_t;

void *theThread(void *parm)
{
    pthread_id_np_t    tid;
    threadParm_t *p = (threadParm_t *)parm;

```

```

        tid = pthread_getthreadid_np();
        printf("Thread ID %.8x, Parameters: %d is the answer to \"%s\"\n",
            tid.intId.lo, p->threadParm1, p->threadParm2);
        return NULL;
    }

int main(int argc, char **argv)
{
    pthread_t      thread;
    int            rc=0;
    threadParm_t   *threadParm;

    printf("Enter Testcase - %s\n", argv[0]);

    threadParm = (threadParm_t *)malloc(sizeof(threadParm));
    threadParm->threadParm1 = 42;
    strcpy(threadParm->threadParm2, "Life, the Universe and Everything");

    printf("Create/start a thread with parameters\n");
    rc = pthread_create(&thread, NULL, theThread, threadParm);
    checkResults("pthread_create()\n", rc);

    printf("Wait for the thread to complete\n");
    rc = pthread_join(thread, NULL);
    checkResults("pthread_join()\n", rc);

    printf("Main completed\n");
    return 0;
}

```

Example: Start a thread using Java

This program shows how to start a thread in a program written in Java.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST11.java

The output of this example is as follows:
Entered the testcase
Create a thread with parameters
Start the thread
Wait for the thread to complete
Thread Parameters: 42 is the answer to "Life, the Universe and Everything"
Testcase completed
*/
import java.lang.*;

public class ATEST11 {

    static class theThread extends Thread {
        int            threadParm1;
        String         threadParm2;

        public theThread(int i, String s) {
            threadParm1 = i;
            threadParm2 = s;
        }
        public void run() {
            System.out.print("Thread Parameters: " + String.valueOf(threadParm1) +
                " is the answer to \"" + threadParm2 + "\"\n");
        }
    }

    public static void main(String argv[]) {

```

```

System.out.print("Entered the testcase\n");

System.out.print("Create a thread with parameters\n");
theThread t = new theThread(42, "Life, the Universe and Everything");

System.out.print("Start the thread\n");
t.start();

System.out.print("Wait for the thread to complete\n");
try {
    t.join();
}
catch (InterruptedException e) {
    System.out.print("Join interrupted\n");
}

System.out.print("Testcase completed\n");
System.exit(0);
}
}

```

End a thread

When a thread has completed its processing, it takes an action to end itself and release system resources for use by other threads.

Some API sets require the application to explicitly release resources associated with the thread when it ends. Other threads implementations (like Java) garbage collect and clean up resources when it is appropriate to do so.

A thread can end in several ways. From a performance perspective, the best way to end a thread is to return from the initial routine that was called when the thread was started. Thread API sets typically provide mechanisms for ending the thread when returning from the initial routine is not an option.

Some API sets also support exception mechanisms. Exception mechanisms for ending a thread result in the thread ending when it takes an exception that is not handled. An example might be a Java exception that is thrown by a thread.

See your language-specific documentation for details on exceptions or other ways a thread can end itself.

Related reference

“Threads as synchronization primitives” on page 43

Threads themselves can be used as synchronization primitives when one thread specifically waits for another thread to complete.

Example: End a thread in a Pthread program

This example shows a Pthread program ending a thread.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
Filename: ATEST12.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST12
Create/start a thread
Wait for the thread to complete, and release its resources
Thread: End with success
Check the thread status
Main completed
*/
#define _MULTI_THREADED

```

```

#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

const int THREADFAIL = 1;
const int THREADPASS = 0;

void *theThread(void *parm)
{
    printf("Thread: End with success\n");
    pthread_exit(__VOID(THREADPASS));
    printf("Thread: Did not expect to get here!\n");
    return __VOID(THREADFAIL);
}

int main(int argc, char **argv)
{
    pthread_t      thread;
    int            rc=0;
    void           *status;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Create/start a thread\n");
    rc = pthread_create(&thread, NULL, theThread, NULL);
    checkResults("pthread_create()\n", rc);

    printf("Wait for the thread to complete, and release its resources\n");
    rc = pthread_join(thread, &status);
    checkResults("pthread_join()\n", rc);

    printf("Check the thread status\n");
    if (__INT(status) != THREADPASS) {
        printf("The thread failed\n");
    }

    printf("Main completed\n");
    return 0;
}

```

Example: End a thread using Java

This is an example of how a thread might be ended using Java.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST12.java

```

The output of this example is as follows:

```

Entered the testcase
Create a thread
Start the thread
Wait for the thread to complete
Thread: End with success
Check the thread status
Testcase completed
*/
import java.lang.*;

```

```

public class ATEST12 {
    static class theThread extends Thread {
        public final static int THREADFAIL = 1;
        public final static int THREADPASS = 0;
        int _status;

        public int status() {
            return _status;
        }
        public theThread() {
            _status = THREADFAIL;
        }
        public void run() {
            System.out.print("Thread: End with success\n");
            _status = THREADPASS;
            /* End the thread without returning */
            /* from its initial routine */
            stop();
            System.out.print("Thread: Didn't expect to get here!\n");
            _status = THREADFAIL;
        }
    }

    public static void main(String argv[]) {
        System.out.print("Entered the testcase\n");

        System.out.print("Create a thread\n");
        theThread t = new theThread();

        System.out.print("Start the thread\n");
        t.start();

        System.out.print("Wait for the thread to complete\n");
        try {
            t.join();
        }
        catch (InterruptedException e) {
            System.out.print("Join interrupted\n");
        }
        System.out.print("Check the thread status\n");
        if (t.status() != theThread.THREADPASS) {
            System.out.print("The thread failed\n");
        }

        System.out.print("Testcase completed\n");
        System.exit(0);
    }
}


```

Cancel a thread

The ability to end a thread externally allows you to cancel threads that run long requests before they are completed on their own. The methods available for canceling threads vary according to the threads API set that is used.

Some API sets provide well-defined points for the cancellation action to occur or other mechanisms that allow one thread to control when another thread ends. Some API sets also provide a mechanism to run cleanup code before the thread ends or to set the result of the canceled thread to a specific value.

Use thread cancellation carefully. If your API set does not provide well-defined cancellation points or a mechanism for the thread to clean up the application data and locks, you might damage data or cause deadlocks within your application.

Note: In Java Development Kit version 1.2 or later, the resume, stop, and suspend methods for the thread class have been deprecated. This is because these methods are considered unsafe. The functions provided by these methods can be implemented by other mechanisms, such as checking the state of some variables. See the Sun Java tutorial at <http://java.sun.com/docs/books/tutorial/>  for the recommended mechanism for a given version of Java.

Related concepts

“Suspend a thread” on page 21

It is sometimes useful to stop a thread temporarily from processing in your application. When you suspend a thread, the state of the thread, including all the attributes and locks held by the thread, is maintained until that thread is resumed.

“Resume a thread” on page 23

If you temporarily stopped a thread from processing in your application, you can resume the processing of the suspended thread at a later time at the same point that you suspended it.

Example: Cancel a thread in a Pthread program

This example shows a Pthread program canceling a long-running thread.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
Filename: ATEST13.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST13
Create/start a thread
Wait a bit until we 'realize' the thread needs to be canceled
Thread: Entered
Thread: Looping or long running request
Thread: Looping or long running request
Thread: Looping or long running request
Wait for the thread to complete, and release its resources
Thread: Looping or long running request
Thread status indicates it was canceled
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

void *theThread(void *parm)
{
    printf("Thread: Entered\n");
    while (1) {
        printf("Thread: Looping or long running request\n");
        pthread_testcancel();
        sleep(1);
    }
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_t      thread;
    int            rc=0;
    void           *status;
```

```

printf("Enter Testcase - %s\n", argv[0]);

printf("Create/start a thread\n");
rc = pthread_create(&thread, NULL, theThread, NULL);
checkResults("pthread_create()\n", rc);

printf("Wait a bit until we 'realize' the thread needs to be canceled\n");
sleep(3);
rc = pthread_cancel(thread);
checkResults("pthread_cancel()\n", rc);

printf("Wait for the thread to complete, and release its resources\n");
rc = pthread_join(thread, &status);
checkResults("pthread_join()\n", rc);

printf("Thread status indicates it was canceled\n");
if (status != PTHREAD_CANCELED) {
    printf("Unexpected thread status\n");
}

printf("Main completed\n");
return 0;
}

```

Example: Cancel a thread using Java

This example shows a Java program canceling a long-running thread.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST13.java

```

```

The output of this example is as follows:
Entered the testcase
Create a thread
Start the thread
Wait a bit until we 'realize' the thread needs to be canceled
Thread: Entered
Thread: Looping or long running request
Thread: Looping or long running request
Thread: Looping or long running request
Wait for the thread to complete
Thread status indicates it was canceled
Testcase completed
*/
import java.lang.*;

```

```

public class ATEST13 {

    static class theThread extends Thread {
        public final static int THREADPASS    = 0;
        public final static int THREADFAIL    = 1;
        public final static int THREADCANCELED = 2;
        int        _status;

        public int status() {
            return _status;
        }
        public theThread() {
            _status = THREADFAIL;
        }
        public void run() {
            System.out.print("Thread: Entered\n");
            try {

```

```

        while (true) {
            System.out.print("Thread: Looping or long running request\n");
            try {
                Thread.sleep(1000);
            }
            catch (InterruptedException e) {
                System.out.print("Thread: sleep interrupted\n");
            }
        }
    }
    catch (ThreadDeath d) {
        _status = THREADCANCELED;
    }
}

public static void main(String argv[]) {
    System.out.print("Entered the testcase\n");

    System.out.print("Create a thread\n");
    theThread t = new theThread();

    System.out.print("Start the thread\n");
    t.start();

    System.out.print("Wait a bit until we 'realize' the thread needs to be canceled\n");
    try {
        Thread.sleep(3000);
    }
    catch (InterruptedException e) {
        System.out.print("sleep interrupted\n");
    }
    t.stop();

    System.out.print("Wait for the thread to complete\n");
    try {
        t.join();
    }
    catch (InterruptedException e) {
        System.out.print("Join interrupted\n");
    }
    System.out.print("Thread status indicates it was canceled\n");
    if (t.status() != theThread.THREADCANCELED) {
        System.out.print("Unexpected thread status\n");
    }

    System.out.print("Testcase completed\n");
    System.exit(0);
}
}

```

Suspend a thread

It is sometimes useful to stop a thread temporarily from processing in your application. When you suspend a thread, the state of the thread, including all the attributes and locks held by the thread, is maintained until that thread is resumed.

Use thread suspension carefully. Suspending threads can easily cause application deadlocks and timeout conditions. You can solve most problems that involve thread suspension by using other safer mechanisms (such as synchronization primitives).

Note: The suspend method of the Java thread class has been deprecated.

Related concepts

“Synchronization techniques among threads” on page 31

When you create code that is threadsafe but still benefits from sharing data or resources between threads, the most important aspect of programming becomes the ability to synchronize threads.

“Cancel a thread” on page 18

The ability to end a thread externally allows you to cancel threads that run long requests before they are completed on their own. The methods available for canceling threads vary according to the threads API set that is used.

Example: Suspend a thread using Java

This example shows a Java program suspending an actively running thread.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
FileName: ATEST14.java

The output of this example is as follows:
Entered the testcase
Create a thread
Start the thread
Wait a bit until we 'realize' the thread needs to be suspended
Thread: Entered
Thread: Active processing
Thread: Active processing
Suspend the thread
Wait a bit until we 'realize' the thread needs to be resumed
Resume the thread
Thread: Active processing
Wait for the thread to complete
Thread: Active processing
Thread: Active processing
Thread: Completed
Testcase completed
*/
import java.lang.*;

public class ATEST14 {

    static class theThread extends Thread {
        public void run() {
            int    loop=6;
            System.out.print("Thread: Entered\n");
            while (--loop > 0) {
                System.out.print("Thread: Active processing\n");
                safeSleep(1000, "Thread: sleep interrupted\n");
            }
            System.out.print("Thread: Completed\n");
        }
    }

    public static void main(String argv[]) {
        System.out.print("Entered the testcase\n");

        System.out.print("Create a thread\n");
        theThread t = new theThread();

        System.out.print("Start the thread\n");
        t.start();

        System.out.print("Wait a bit until we 'realize' the thread needs to be suspended\n");
        safeSleep(2000, "Main first sleep interrupted\n");
        System.out.print("Suspend the thread\n");
        t.suspend();
    }
}
```

```

        System.out.print("Wait a bit until we 'realize' the thread needs to be resumed\n");
        safeSleep(2000, "Main second sleep interrupted\n");
        System.out.print("Resume the thread\n");
        t.resume();

        System.out.print("Wait for the thread to complete\n");
        try {
            t.join();
        }
        catch (InterruptedException e) {
            System.out.print("Join interrupted\n");
        }

        System.out.print("Testcase completed\n");
        System.exit(0);
    }

    public static void safeSleep(long milliseconds, String s) {
        try {
            Thread.sleep(milliseconds);
        }
        catch (InterruptedException e) {
            System.out.print(s);
        }
    }
}

```

Resume a thread

If you temporarily stopped a thread from processing in your application, you can resume the processing of the suspended thread at a later time at the same point that you suspended it.

The resumed thread holds the same locks and has the same attributes that it had when you suspended it.

Note: The suspend method of the Java thread class has been deprecated.

Related concepts

“Cancel a thread” on page 18

The ability to end a thread externally allows you to cancel threads that run long requests before they are completed on their own. The methods available for canceling threads vary according to the threads API set that is used.

Wait for a thread to end

When using threads, it is important to know when a thread has finished processing. Waiting for a thread to perform an action or an event to happen is called thread synchronization.

It is typically sufficient to wait for a thread to end. When the thread ends, the application is alerted that the work the thread was assigned is complete or the thread failed. If a status is set by the thread and is supported by your specific API set, you can use the status to determine whether the thread successfully completed its work.

When a thread ends, the system reclaims its resources for reuse. You can also wait for a thread to end to reclaim more of the thread’s resources for use by other threads.

Waiting for a group of threads to end can also be a good way for a larger application, such as a server, to give large amounts of application work to “worker” threads and have a single “boss” thread coordinate the work of the subordinate threads. Your API set can directly support this kind of waiting.

Example: Wait for threads in a Pthread program

This example shows a Pthread program starting several threads, waiting for them to finish, and checking their status after they complete.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
Filename: ATEST13.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST15
Create/start some worker threads
Thread 00000000 000001a4: Entered
Thread 00000000 000001a4: Working
Wait for worker threads to complete, release their resources
Thread 00000000 000001a8: Entered
Thread 00000000 000001a8: Working
Thread 00000000 000001a5: Entered
Thread 00000000 000001a5: Working
Thread 00000000 000001a6: Entered
Thread 00000000 000001a6: Working
Thread 00000000 000001a7: Entered
Thread 00000000 000001a7: Working
Thread 00000000 000001a4: Done with work
Thread 00000000 000001a8: Done with work
Thread 00000000 000001a6: Done with work
Thread 00000000 000001a7: Done with work
Thread 00000000 000001a5: Done with work
Check all thread's results
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define THREADGROUPSIZE 5

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

void *theThread(void *parm)
{
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    printf("Thread %.8x %.8x: Working\n", pthread_getthreadid_np());
    sleep(15);
    printf("Thread %.8x %.8x: Done with work\n", pthread_getthreadid_np());
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_t      thread[THREADGROUPSIZE];
    void           *status[THREADGROUPSIZE];
    int            i;
    int            rc=0;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Create/start some worker threads\n");
    for (i=0; i <THREADGROUPSIZE; ++i)
    {
```

```

    rc = pthread_create(&thread[i], NULL, theThread, NULL);
    checkResults("pthread_create()\n", rc);
}

printf("Wait for worker threads to complete, release their resources\n");
for (i=0; i <THREADGROUPSIZE; ++i) {
rc = pthread_join(thread[i], &status[i]);
    checkResults("pthread_join()\n", rc);
}

printf("Check all thread's results\n");
for (i=0; i <THREADGROUPSIZE; ++i) {
if (status[i] != NULL) {
    printf("Unexpected thread status\n");
}
}

printf("Main completed\n");
return 0;
}

```

Example: Wait for threads using Java

This example shows a Java program starting several threads, waiting for them to finish, and checking their status after completion.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST15.java

The output of this example is as follows:
Entered the testcase
Create some worker threads
Start the thread
Thread Thread-1: Entered
Thread Thread-1: Working
Thread Thread-2: Entered
Thread Thread-2: Working
Thread Thread-3: Entered
Thread Thread-3: Working
Thread Thread-4: Entered
Thread Thread-4: Working
Wait for worker threads to complete
Thread Thread-5: Entered
Thread Thread-5: Working
Thread Thread-1: Done with work
Thread Thread-2: Done with work
Thread Thread-3: Done with work
Thread Thread-4: Done with work
Thread Thread-5: Done with work
Check all thread's results
Testcase completed
*/
import java.lang.*;

public class ATEST15 {
    public final static int THREADGROUPSIZE = 5;

    static class theThread extends Thread {
        public final static int THREADPASS = 0;
        public final static int THREADFAIL = 1;
        int _status;

        public int status() {
            return _status;
        }
    }
}

```

```

    }
    public theThread() {
        _status = THREADFAIL;
    }
    public void run() {
        System.out.print("Thread " + getName() + ": Entered\n");
        System.out.print("Thread " + getName() + ": Working\n");
        safeSleep(15000, "Thread " + getName() + " work");
        System.out.print("Thread " + getName() + ": Done with work\n");
        _status = THREADPASS;
    }
}

public static void main(String argv[]) {
    int i=0;
    theThread thread[] = new theThread[THREADGROUPSIZE];

    System.out.print("Entered the testcase\n");

    System.out.print("Create some worker threads\n");
    System.out.print("Start the thread\n");
    /* We won't use a ThreadGroup for this example, because we'd */
    /* still have to join all the threads individually */
    for (i=0; i <THREADGROUPSIZE; ++i) {
thread[i] = new theThread();
        thread[i].start();
    }

    System.out.print("Wait for worker threads to complete\n");
    for (i=0; i <THREADGROUPSIZE; ++i) {
try {
        thread[i].join();
    }
    catch (InterruptedException e) {
        System.out.print("Join interrupted\n");
    }
    }
    System.out.print("Check all thread's results\n");
    for (i=0; i <THREADGROUPSIZE; ++i) {
if (thread[i].status() != theThread.THREADPASS) {
        System.out.print("Unexpected thread status\n");
    }
    }

    System.out.print("Testcase completed\n");
    System.exit(0);
}

public static void safeSleep(long milliseconds, String s) {
    try {
        Thread.sleep(milliseconds);
    }
    catch (InterruptedException e) {
        System.out.print(s);
    }
}
}

```

Yield the processor to another thread

At times, your application can benefit when a thread yields the processor to another thread in the system.

When a thread yields the processor, it immediately allows another equal or higher priority thread that is active in the system to run. If no threads of at least equal priority are currently ready to run, yielding the

processor has no effect. Beyond the immediate action, yielding the processor does not have any additional predictable behavior related to the scheduling of the threads in the system.

The iSeries server provides a fully preemptive multitasking scheduling algorithm. A thread that exists in a well-written application should seldom need to yield the processor to other threads. This is because more predictable application programming interfaces (APIs) for synchronizing threads are available.

Thread safety

A function is threadsafe if you can start it simultaneously in multiple threads within the same process. A function is threadsafe if and only if all the functions it calls are also threadsafe.

Related concepts

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

Related reference

“Activation groups and threads” on page 4

All programs and service programs are activated within a substructure of a job that is called an activation group. This substructure contains the resources necessary to run the programs, including static and heap storage, and temporary data management resources.

“Existing application evaluation” on page 31

When writing a multithreaded application, you should evaluate all the parts of the application and all the services that it uses for thread safety.

Storage usage and threaded applications

When writing a threaded application, it is important to understand the visibility and scope of various classes of storage.

When your application declares variables, multiple threads might be able to access or use them. The visibility and scope of the storage it uses often affect your application.

- Global storage:

Global storage that you declare in one of your application source files is visible to all other source files or modules in your application. All threads that run code in your application share the same global storage. This unintended sharing of storage is a common safety problem.

- Static storage:

Static storage is global storage with visibility that is restricted to the source file, module, or function in which the storage or variable was declared. All threads that run code from that module share the same static storage.

- Heap storage:

Heap storage is allocated and deallocated dynamically by your application (for example, by `malloc()` and `free()` in C, or `new` and `delete` in Java or C++). All threads that run code in your application share the same heap.

If you give another thread a pointer to the heap storage that has been allocated (by storing the pointer in static or global storage, or by otherwise passing the pointer to another thread) that thread can use or deallocate the storage. This unintended sharing of storage is a common thread safety problem.

- Automatic storage:

Automatic or local storage is allocated automatically by your language when you declare a variable that is private to a function, method, or subroutine. Local storage is not visible to other threads in the process. Each time those threads call the function, method, or subroutine, the thread allocates new versions of the automatic variables. Each thread gets its own automatic storage. A thread should not access automatic storage from another thread because of the complex serialization and synchronization issues involved.

The operating system further restricts the scope of global, static, and heap storage to the activation group that your application code is running in. This means that application code or threads running in different activation groups but using the same global or static variables access different versions of those variables and their storage. Similarly, heap storage allocated in one activation group might not be de-allocated in a different activation group although it can be used by different activation groups.

Some languages support only global or static storage classes for variables. These languages are not easy to use in threaded applications. You should not use threads in these languages.

Job-scoped resources and thread safety

Many system and application resources are available only within a defined job. When writing a multithreaded application or service, you must evaluate your use of job-scoped resources. The use of these resources must not conflict with or negatively affect other threads in the process.

Some resources (open database files, for example) are scoped to the activation group. For the purposes of this discussion, resources that are scoped to the activation group must be treated with the same considerations as job-scoped resources. All of the threads that use the activation group use them.

Your application can use appropriate synchronization techniques if threads in your application modify these resources while other threads are using them, and you need to ensure a consistent view of the resources between your threads.

Some of the common job-scoped or activation group-scoped resources are as follows:

- Heap, static, and global storage:
The most commonly shared resource. For more information, see the section about storage usage.
- Open files:
After you open a file, threads in a process can directly share integrated file system file and database files by passing the file handle pointer or file descriptor number to another thread. The working directory is always scoped to the process.
- Locales:
The locale of an application is an activation group resource. All threads share the locale. Changing the locale affects other threads with regard to collating sequences or other locale information.
- Coded character set identifier:
Changing the coded character set identifier (CCSID) of a job affects the current data translation or representation of all threads in that job.
- Environment variables:
Your application commonly uses environment variables for configuration and optional behavior. All the threads in the job share them.

API thread safety classifications

Before using an API, you should determine if it is safe to call that API in your multithreaded program.

Each API has a threadsafe classification. The three types of threadsafe classifications are as follows:

- Threadsafes: yes
This classification indicates that you can safely call the API simultaneously in multiple threads without restrictions. This classification also indicates that all functions called by this API are threadsafe.
- Threadsafes: conditional
This classification indicates that not all functions provided by the API are threadsafe. The Usage Notes section of the API provides information that relates to thread safety limitations. Many APIs are classified conditionally threadsafe because either some underlying system support is not threadsafe or the API can call an exit point. For example, many of the file system APIs are completely threadsafe

when used with files in a threadsafe file system. Some conditionally threadsafe APIs might deny access under some circumstances. The API usage notes describe the conditions that cause the function to deny access.

- Threadsafes: no

This classification indicates that the API is not threadsafe and that the API should not be used in a multithreaded program. While some APIs that are not threadsafe might deny access, most APIs that are not threadsafe do not. Unlike in CL commands, no diagnostic message is in the job log to indicate that an API that is not threadsafe has been called (other than APIs that deny access). There are techniques for calling functions that are not threadsafe in multithreaded programs.

Related information

Application Programming Interfaces

CL commands and thread safety

The Integrated Language Environment (ILE) CL run time and compiler-generated code are threadsafe. Original program model (OPM) CL programs are not threadsafe.

For any ILE CL code that is compiled before Version 4 Release 3 or any OPM CL code, the CL run time sends a CPD000B diagnostic message and continues to run with unpredictable results. This might or might not be threadsafe, depending on the underlying code.

Command analyzer is threadsafe. For a given command, if the threadsafe attribute (THDSAFE) is *NO and the multithreaded job action attribute (MLTTHDACN) is set to *NORUN or *MSG, the command analyzer does one of the following when such a command is called in a job capable of multithreaded operations:

- If MLTTHDACN is set to *NORUN in a multithreaded job, command analyzer sends a CPD000D diagnostic message, and the command does not run. A CPF0001 escape message then follows the CPD000D diagnostic message.
- If MLTTHDACN is set to *MSG in a multithreaded job, command analyzer sends a CPD000D diagnostic message, and the program continues to run with unpredictable results.
- If the job is capable of running multiple threads but is not actually multithreaded, command analyzer allows commands that are not threadsafe to run without interference.

If MLTTHDACN is set to *RUN, the command analyzer does not send a diagnostic message and allows the command to run. The results of this are unpredictable. Also, MLTTHDACN only applies to comments whose THDSAFE value is *NO. To determine the THDSAFE and MLTTHDACN values for a command, use Display Command (DSPCMD).

The MLTTHDACN value of some commands is set to *SYSVAL. In this case, command analyzer uses the QMLTTHDACN system value to decide how to process the command.

To display the setting of this value on i5/OS:

```
DSPSYSVAL SYSVAL(QMLTTHDACN)
```

To change the setting of this value on i5/OS:

```
CHGSYSVAL SYSVAL(QMLTTHDACN) VALUE(x)
```

Sample output from DSPSYSVAL:

```
Display System Value
```

```
System value . . . . . : QMLTTHDACN
Description . . . . . : Multithreaded job action
```

Multithreaded job
action : 2
1=Perform the function that is not
threadsafe without sending a message
2=Perform the function that is not
threadsafe and send an informational
message
3=Do not perform the function that is
not threadsafe

Related concepts

“Multithreaded programming techniques” on page 31

If you are going to write multithreaded applications or server applications for i5/OS, you should be familiar with several techniques.

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

Denied access functions and thread safety

To prevent problems in system integrity and data damages, certain APIs and commands are either conditionally threadsafe or not threadsafe. These APIs and commands deny all or partial access.

The criteria for denying access are as follows:

- Multithread capability:

In this case, the decision to deny access to a function is made by checking the multithread-capable job attribute. If the job is capable of supporting threads, regardless of the current number of threads in the job, you cannot call the function. When a function denies access based on multithread capability, it sends a CPF1892 (Function &1 not allowed) escape message to the caller. You must call functions that deny access based on multithread capability in separate jobs or not at all.

- Initial thread:

Some functions deny access based on whether the initial thread of the job calls the function. If you call the function in a secondary thread, the function denies access by sending a CPF180C (Function &1 not allowed) escape message to the caller. You can call a function that denies access from a secondary thread by routing a request to the initial thread and having the function called in the initial thread. Overriding a database file is an example of a function that is only allowed in the initial thread.

- More than one thread:

In this case, the number of threads in the job causes the decision to deny access. If more than one thread is in the job, the function sends a CPF180B (Function &1 not allowed) escape message to the caller. Other functions that return error numbers sets errno to ENOTSAFE.

You can call a function that denies access when there are multiple threads by restricting its use to when only one thread is active. An example of such a function is any file system API that is used to access a file in a file system that is not threadsafe.

Related information

Reclaim Resources (RCLRCS) command

Exit points

The i5/OS registration facility allows you to define exit points for functions in an application and to register programs that run at those exit points.

Some i5/OS services also support the registration facility for registering exit programs. They have predefined exit points that are registered when those services are installed. The registration facility itself is threadsafe. You can use it to specify attributes of thread safety and multithreaded job actions for exit program entries.

Without careful evaluation, however, you should not consider existing exit programs to be threadsafe, even though you can call exit programs in a multithreaded job. The same restrictions apply to exit programs as to any other code that runs in a multithreaded job. For example, only exit programs written using a threadsafe Integrated Language Environment (ILE) language that can be made threadsafe.

Related reference

“Existing application evaluation”

When writing a multithreaded application, you should evaluate all the parts of the application and all the services that it uses for thread safety.

“Database considerations for multithreaded programming” on page 5

You should consider these items when using databases in multithreaded programs.

Multithreaded programming techniques

If you are going to write multithreaded applications or server applications for i5/OS, you should be familiar with several techniques.

The concepts that are described in this section pertain to all programming languages. To determine how each language enables these concepts, refer to the Language topic in the information center for the specific language.

Related reference

“CL commands and thread safety” on page 29

The Integrated Language Environment (ILE) CL run time and compiler-generated code are threadsafe. Original program model (OPM) CL programs are not threadsafe.

Existing application evaluation

When writing a multithreaded application, you should evaluate all the parts of the application and all the services that it uses for thread safety.

How each service or API that is used by the application uses its storage resources is an important consideration for providing threadsafe applications. If you do not use storage in a threadsafe manner, data in your application is likely to be damaged.

Other critical aspects in creating threadsafe applications are the APIs and system services on which your application or your application services rely. To be threadsafe, your storage usage and all APIs and services that you use directly or indirectly must be threadsafe. APIs and system resources that you use indirectly are particularly difficult to evaluate. See the APIs topic for the specific APIs or system services you use to see if they are thread safe.

You will probably call system services, APIs, or other applications for which you do not have the source code. Many of these services are not be classified as threadsafe or non-threadsafe. You must assume that the services are not threadsafe.

Related concepts

“Thread safety” on page 27

A function is threadsafe if you can start it simultaneously in multiple threads within the same process. A function is threadsafe if and only if all the functions it calls are also threadsafe.

Related reference

“Exit points” on page 30

The i5/OS registration facility allows you to define exit points for functions in an application and to register programs that run at those exit points.

Synchronization techniques among threads

When you create code that is threadsafe but still benefits from sharing data or resources between threads, the most important aspect of programming becomes the ability to synchronize threads.

Synchronization is the cooperative act of two or more threads that ensures that each thread reaches a known point of operation in relationship to other threads before continuing. Attempting to share resources without correctly using synchronization is the most common cause of damage to application data.

Typically, synchronizing two threads involves the use of one or more synchronization primitives. Synchronization primitives are low-level functions or application objects (not i5/OS objects) that your application used or created to provide the synchronization behavior the application requires.

The most common synchronization primitives are as follows, in order of least to most computationally expensive:

- Compare and swap
- Mutual exclusion (mutexes) and threads
- Semaphores and threads
- Condition variables and threads
- Threads as synchronization primitives
- Space location locks
- Object locks

These concepts pertain to all programming languages. To determine how each language enables these concepts, refer to the Language topic in the information center for the specific language.

Related concepts

“Suspend a thread” on page 21

It is sometimes useful to stop a thread temporarily from processing in your application. When you suspend a thread, the state of the thread, including all the attributes and locks held by the thread, is maintained until that thread is resumed.

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

Mutexes and threads

A mutual exclusion (mutex) is used cooperatively between threads to ensure that only one of the cooperating threads is allowed to access the data or run certain application code at a time.

The word mutex is shorthand for a primitive object that provides MUTual EXclusion between threads. For the purposes of this introduction, you can think of mutexes as similar to critical sections and monitors.

The mutex is typically logically associated with the data it protects by the application. For example, PAYROLL DATA has a PAYROLL MUTEX associated with it. The application code always locks the PAYROLL MUTEX before accessing the PAYROLL DATA. The mutex prevents access to the data by a thread only if that thread uses the mutex before accessing the data.

Create, lock, unlock, and destroy are operations typically performed on a mutex. Any thread that successfully locks the mutex is the owner until it unlocks the mutex. Any thread that attempts to lock the mutex waits until the owner unlocks the mutex. When the owner unlocks the mutex, control is returned to one waiting thread with that thread becoming the owner of the mutex. There can be only one owner of a mutex.

Mutex wait operations can be recursive. Recursive mutexes allow the owner to lock the mutex repeatedly. The owner of the mutex remains the same until the number of unlock requests is the same as the number of successful lock requests. Mutex waits can time out after a user specified amount of time or can return immediately if they cannot acquire the lock. For more information, see your API set documentation about mutex primitives available for your application.

Example: Use mutexes in Pthread programs:

This example shows a Pthread program starting several threads that protect access to shared data with a mutual exclusion (mutex).

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
Filename: ATEST16.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST16
Hold Mutex to prevent access to shared data
Create/start threads
Wait a bit until we are 'done' with the shared data
Thread 00000000 00000019: Entered
Thread 00000000 0000001a: Entered
Thread 00000000 0000001b: Entered
Unlock shared data
Wait for the threads to complete, and release their resources
Thread 00000000 00000019: Start critical section, holding lock
Thread 00000000 00000019: End critical section, release lock
Thread 00000000 0000001a: Start critical section, holding lock
Thread 00000000 0000001a: End critical section, release lock
Thread 00000000 0000001b: Start critical section, holding lock
Thread 00000000 0000001b: End critical section, release lock
Clean up
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

#define NUMTHREADS 3
pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
int sharedData=0;
int sharedData2=0;

void *theThread(void *parm)
{
    int rc;
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    rc = pthread_mutex_lock(&mutex);
    checkResults("pthread_mutex_lock()\n", rc);
    /****** Critical Section *****/
    printf("Thread %.8x %.8x: Start critical section, holding lock\n",
        pthread_getthreadid_np());
    /* Access to shared data goes here */
    ++sharedData; --sharedData2;
    printf("Thread %.8x %.8x: End critical section, release lock\n",
        pthread_getthreadid_np());
    /****** Critical Section *****/
    rc = pthread_mutex_unlock(&mutex);
    checkResults("pthread_mutex_unlock()\n", rc);
    return NULL;
}

int main(int argc, char **argv)
```



```

{
pthread_t          thread[NUMTHREADS];
int                rc=0;
int                i;

printf("Enter Testcase - %s\n", argv[0]);

printf("Hold Mutex to prevent access to shared data\n");
rc = pthread_mutex_lock(&mutex);
checkResults("pthread_mutex_lock()\n", rc);

printf("Create/start threads\n");
for (i=0; i<NUMTHREADS; ++i) {
rc = pthread_create(&thread[i], NULL, theThread, NULL);
checkResults("pthread_create()\n", rc);
}

printf("Wait a bit until we are 'done' with the shared data\n");
sleep(3);
printf("Unlock shared data\n");
rc = pthread_mutex_unlock(&mutex);
checkResults("pthread_mutex_unlock()\n",rc);

printf("Wait for the threads to complete, and release their resources\n");
for (i=0; i <NUMTHREADS; ++i) {
rc = pthread_join(thread[i], NULL);
checkResults("pthread_join()\n", rc);
}

printf("Clean up\n");
rc = pthread_mutex_destroy(&mutex);
printf("Main completed\n");
return 0;
}

```

Example: Use mutexes in Java:

This example shows a Java program creating a critical section of code. In Java, any object or array can function similarly to a mutual exclusion (mutex) using the synchronized keyword on a block of code or a method.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST16.java
The output of this example is as follows:
Entered the testcase
Synchronize to prevent access to shared data
Create/start the thread
Thread Thread-1: Entered
Thread Thread-2: Entered
Wait a bit until we're 'done' with the shared data
Thread Thread-3: Entered
Unlock shared data
Thread Thread-1: Start critical section, in synchronized block
Thread Thread-1: End critical section, leave synchronized block
Thread Thread-2: Start critical section, in synchronized block
Thread Thread-2: End critical section, leave synchronized block
Thread Thread-3: Start critical section, in synchronized block
Thread Thread-3: End critical section, leave synchronized block
Wait for the threads to complete
Testcase completed
*/
import java.lang.*;

```



```

public class ATEST16 {
    public final static int NUMTHREADS    = 3;
    public static int sharedData    = 0;
    public static int sharedData2    = 0;
    /* Any real java object or array would suit for synchronization    */
    /* We invent one here since we have two unique data items to synchronize */
    /* An in this simple example, they're not in an object                */
    static class theLock extends Object {
    }
    static public theLock lockObject = new theLock();

    static class theThread extends Thread {
        public void run() {
            System.out.print("Thread " + getName() + ": Entered\n");
            synchronized (lockObject) {
                /****** Critical Section *****/
                System.out.print("Thread " + getName() +
                    ": Start critical section, in synchronized block\n");
                ++sharedData; --sharedData2;
                System.out.print("Thread " + getName() +
                    ": End critical section, leave synchronized block\n");
                /****** Critical Section *****/
            }
        }
    }

    public static void main(String argv[]) {
        theThread threads[] = new theThread[NUMTHREADS];
        System.out.print("Entered the testcase\n");

        System.out.print("Synchronize to prevent access to shared data\n");
        synchronized (lockObject) {

            System.out.print("Create/start the thread\n");
            for (int i=0; i<NUMTHREADS; ++i) {
                threads[i] = new theThread();
                threads[i].start();
            }

            System.out.print("Wait a bit until we're 'done' with the shared data\n");
            try {
                Thread.sleep(3000);
            }
            catch (InterruptedException e) {
                System.out.print("sleep interrupted\n");
            }
            System.out.print("Unlock shared data\n");
        }

        System.out.print("Wait for the threads to complete\n");
        for(int i=0; i < NUMTHREADS; ++i) {
            threads[i].join();
        }
        catch (InterruptedException e) {
            System.out.print("Join interrupted\n");
        }
    }

    System.out.print("Testcase completed\n");
    System.exit(0);
}
}

```

Semaphores and threads

Semaphores (sometimes referred to as counting semaphores) can be used to control access to shared resources. A semaphore can be thought of as an intelligent counter. Every semaphore has a current count, which is greater than or equal to 0.

Any thread can decrement the count to lock the semaphore (this is also called waiting on the semaphore). Attempting to decrement the count past 0 causes the thread that is calling to wait for another thread to unlock the semaphore.

Any thread can increment the count to unlock the semaphore (this is also called posting the semaphore). Posting a semaphore might wake up a waiting thread if there is one present.

In their simplest form (with an initial count of 1), semaphores can be thought of as a mutual exclusion (mutex). The important distinction between semaphores and mutexes is the concept of ownership. No ownership is associated with a semaphore. Unlike mutexes, it is possible for a thread that never waited for (locked) the semaphore to post (unlock) the semaphore. This can cause unpredictable application behavior. You should avoid this if possible.

Additional capabilities of some semaphore APIs provided by the operating system are as follows:

- More complete management capabilities, including permissions on semaphores that are similar to file permissions.
- The ability to group semaphores in sets and perform atomic operations on the group
- The ability to do multicount wait and post operations
- The ability to wait for a semaphore to have a count of 0
- The ability to undo operations that are done by another thread under certain conditions

Note: Java does not have the ability to use semaphores.

Example: Use semaphores in Pthread programs to protect shared data:

This example shows a Pthread program starting several threads that protect access to shared data with a semaphore set.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
Filename: ATEST17.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST17
Wait on semaphore to prevent access to shared data
Create/start threads
Wait a bit until we are 'done' with the shared data
Thread 00000000 00000020: Entered
Thread 00000000 0000001f: Entered
Thread 00000000 0000001e: Entered
Unlock shared data
Wait for the threads to complete, and release their resources
Thread 00000000 0000001f: Start critical section, holding semaphore
Thread 00000000 0000001f: End critical section, release semaphore
Thread 00000000 00000020: Start critical section, holding semaphore
Thread 00000000 00000020: End critical section, release semaphore
Thread 00000000 0000001e: Start critical section, holding semaphore
Thread 00000000 0000001e: End critical section, release semaphore
Clean up
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
```

```

#include <stdio.h>
#include <stdlib.h>
#include <errno.h>
#include <unistd.h>
#include <sys/ipc.h>
#include <sys/sem.h>
#include <sys/stat.h>

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

#define NUMTHREADS 3
int sharedData=0;
int sharedData2=0;

/* Simple semaphore used here is actually a set of 1 */
int semaphoreId=-1;
/* Simple lock operation. 0=which-semaphore, -1=decrement, 0=noflags */
struct sembuf lockOperation = { 0, -1, 0};
/* Simple unlock operation. 0=which-semaphore, 1=increment, 0=noflags */
struct sembuf unlockOperation = { 0, 1, 0};

void *theThread(void *parm)
{
    int rc;
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    rc = semop(semaphoreId, &lockOperation, 1);
    checkResults("semop(lock)\n",rc);
    /****** Critical Section *****/
    printf("Thread %.8x %.8x: Start critical section, holding semaphore\n",
        pthread_getthreadid_np());
    /* Access to shared data goes here */
    ++sharedData; --sharedData2;
    printf("Thread %.8x %.8x: End critical section, release semaphore\n",
        pthread_getthreadid_np());
    /****** Critical Section *****/
    rc = semop(semaphoreId, &unlockOperation, 1);
    checkResults("semop(unlock)\n",rc);
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_t thread[NUMTHREADS];
    int rc=0;
    int i;

    printf("Enter Testcase - %s\n", argv[0]);
    /* Create a private semaphore set with 1 semaphore that only I can use */
    semaphoreId = semget(IPC_PRIVATE, 1, S_IRUSR|S_IWUSR);
    if (semaphoreId &lt; 0) { printf("semget failed, err=%d\n",errno); exit(1); }
    /* Set the semaphore (#0 in the set) count to 1. Simulate a mutex */
    rc = semctl(semaphoreId, 0, SETVAL, (int)1);
    checkResults("semctl(SETALL)\n", rc);

    printf("Wait on semaphore to prevent access to shared data\n");
    rc = semop(semaphoreId, &lockOperation, 1);
    checkResults("semop(lock)\n",rc);

    printf("Create/start threads\n");
    for (i=0; i <NUMTHREADS; ++i) {
        checkResults("pthread_create()\n", rc);

```

```

}

printf("Wait a bit until we are 'done' with the shared data\n");
sleep(3);
printf("Unlock shared data\n");
rc = semop(semaphoreId, &unlockOperation, 1);
checkResults("semop(unlock)\n",rc);

printf("Wait for the threads to complete, and release their resources\n");
for (i=0; i < NUMTHREADS; ++i) {
rc = pthread_join(thread[i], NULL);
checkResults("pthread_join()\n", rc);
}

printf("Clean up\n");
rc = semctl(semaphoreId, 0, IPC_RMID);
checkResults("semctl(removeID)\n", rc);
printf("Main completed\n");
return 0;
}

```

Condition variables and threads

Condition variables allow threads to wait for certain events or conditions to occur and they notify other threads that are also waiting for the same events or conditions.

The thread can wait on a condition variable and broadcast a condition such that one or all of the threads that are waiting on the condition variable become active. You can consider condition variables to be similar to using events to synchronize threads on other platforms.

Condition variables do not have ownership associated with them and are typically stateless. A stateless condition variable means that if a thread signals a condition variable to wake up a waiting thread when there are currently no waiting threads, the signal is discarded and no action is taken. The signal is effectively lost. It is possible for one thread to signal a condition immediately before a different thread begins waiting for it without any resulting action.

Locking protocols that use mutual exclusions (mutexes) are typically used with condition variables. If you use locking protocols, your application can ensure that a thread does not lose a signal that was intended to wake it up.

Example: Use condition variables in Pthread programs:

This example shows a Pthread program using condition variables to notify threads of a condition. Notice what mutual exclusion (mutex) locking protocol is used.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
Filename: ATEST18.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST18
Create/start threads
Producer: 'Finding' data
Consumer Thread 00000000 00000022: Entered
Consumer Thread 00000000 00000023: Entered
Consumer Thread 00000000 00000022: Wait for data to be produced
Consumer Thread 00000000 00000023: Wait for data to be produced
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Producer: 'Finding' data
Consumer Thread 00000000 00000022: Found data or Notified, CONSUME IT while holding lock
Consumer Thread 00000000 00000022: Wait for data to be produced

```

```

Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Producer: 'Finding' data
Consumer Thread 00000000 00000023: Found data or Notified, CONSUME IT while holding lock
Consumer Thread 00000000 00000023: Wait for data to be produced
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Producer: 'Finding' data
Consumer Thread 00000000 00000022: Found data or Notified, CONSUME IT while holding lock
Consumer Thread 00000000 00000022: All done
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Wait for the threads to complete, and release their resources
Consumer Thread 00000000 00000023: Found data or Notified, CONSUME IT while holding lock
Consumer Thread 00000000 00000023: All done
Clean up
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

#define NUMTHREADS 2
pthread_mutex_t dataMutex = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t dataPresentCondition = PTHREAD_COND_INITIALIZER;
int dataPresent=0;
int sharedData=0;

void *theThread(void *parm)
{
    int rc;
    int retries=2;

    printf("Consumer Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    rc = pthread_mutex_lock(&dataMutex);
    checkResults("pthread_mutex_lock()\n", rc);

    while (retries-- > 0) {
        /* The boolean dataPresent value is required for safe use of */
        /* condition variables. If no data is present we wait, other */
        /* wise we process immediately. */
        while (!dataPresent) {
            printf("Consumer Thread %.8x %.8x: Wait for data to be produced\n");
            rc = pthread_cond_wait(&dataPresentCondition, &dataMutex);
            if (rc) {
                printf("Consumer Thread %.8x %.8x: condwait failed, rc=%d\n",rc);
                pthread_mutex_unlock(&dataMutex);
                exit(1);
            }
        }
        printf("Consumer Thread %.8x %.8x: Found data or Notified, "
            "CONSUME IT while holding lock\n",
            pthread_getthreadid_np());
        /* Typically an application should remove the data from being */
        /* in the shared structure or Queue, then unlock. Processing */
        /* of the data does not necessarily require that the lock is held */
        /* Access to shared data goes here */
        --sharedData;
    }
}

```

```

    /* We consumed the last of the data */
    if (sharedData==0) {dataPresent=0;}
    /* Repeat holding the lock. pthread_cond_wait releases it atomically */
}
printf("Consumer Thread %.8x %.8x: All done\n",pthread_getthreadid_np());
rc = pthread_mutex_unlock(&dataMutex);
checkResults("pthread_mutex_unlock()\n", rc);
return NULL;
}

int main(int argc, char **argv)
{
    pthread_t      thread[NUMTHREADS];
    int            rc=0;
    int            amountOfData=4;
    int            i;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Create/start threads\n");
    for (i=0; i <NUMTHREADS; ++i) {
rc = pthread_create(&thread[i], NULL, theThread, NULL);
    checkResults("pthread_create()\n", rc);
    }

    /* The producer loop */
    while (amountOfData-->0) {
        printf("Producer: 'Finding' data\n");
        sleep(3);

        rc = pthread_mutex_lock(&dataMutex); /* Protect shared data and flag */
        checkResults("pthread_mutex_lock()\n", rc);
        printf("Producer: Make data shared and notify consumer\n");
        ++sharedData; /* Add data */
        dataPresent=1; /* Set boolean predicate */

        rc = pthread_cond_signal(&dataPresentCondition); /* wake up a consumer */
        if (rc) {
            pthread_mutex_unlock(&dataMutex);
            printf("Producer: Failed to wake up consumer, rc=%d\n", rc);
            exit(1);
        }

        printf("Producer: Unlock shared data and flag\n");
        rc = pthread_mutex_unlock(&dataMutex);
        checkResults("pthread_mutex_unlock()\n",rc);
    }

    printf("Wait for the threads to complete, and release their resources\n");
    for (i=0; i <NUMTHREADS; ++i) {
rc = pthread_join(thread[i], NULL);
    checkResults("pthread_join()\n", rc);
    }

    printf("Clean up\n");
    rc = pthread_mutex_destroy(&dataMutex);
    rc = pthread_cond_destroy(&dataPresentCondition);
    printf("Main completed\n");
    return 0;
}

```

Example: Use condition variables in Java programs:

This example shows a Java program using condition variables in the form of the wait and notify methods on a Java object. Note the locking protocol used.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
FileName: ATEST18.java
The output of this example is as follows:
Entered the testcase
Create/start the thread
Consumer Thread-1: Entered
Consumer Thread-1: Wait for the data to be produced
Producer: 'Finding data
Consumer Thread-2: Entered
Consumer Thread-2: Wait for the data to be produced
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Consumer Thread-2: Found data or notified, CONSUME IT while holding inside the monitor
Consumer Thread-2: Wait for the data to be produced
Producer: 'Finding data
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Producer: 'Finding data
Consumer Thread-2: Found data or notified, CONSUME IT while holding inside the monitor
Consumer Thread-2: All done
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Producer: 'Finding data
Consumer Thread-1: Found data or notified, CONSUME IT while holding inside the monitor
Consumer Thread-1: Wait for the data to be produced
Producer: Make data shared and notify consumer
Producer: Unlock shared data and flag
Wait for the threads to complete
Consumer Thread-1: Found data or notified, CONSUME IT while holding inside the monitor
Consumer Thread-1: All done
Testcase completed
*/
import java.lang.*;

/* This class is an encapsulation of the condition variable plus */
/* mutex locking logic that can be seen in the Pthread example */
class theSharedData extends Object {
    int          dataPresent;
    int          sharedData;

    public theSharedData() {
        dataPresent=0;
        sharedData=0;
    }
    public synchronized void get() {
        while (dataPresent == 0) {
            try {
                System.out.print("Consumer " +
                                Thread.currentThread().getName() +
                                ": Wait for the data to be produced\n");

                wait();
            }
            catch (InterruptedException e) {
                System.out.print("Consumer " +
                                Thread.currentThread().getName() +
                                ": wait interrupted\n");
            }
        }
        System.out.print("Consumer " +
                        Thread.currentThread().getName() +
                        ": Found data or notified, CONSUME IT " +
                        "while holding inside the monitor\n");
        --sharedData;
        if (sharedData == 0) {dataPresent=0;}
    }
}
```

```

    /* in a real world application, the actual data would be returned */
    /* here                                                                 */
}
public synchronized void put() {
    System.out.print("Producer: Make data shared and notify consumer\n");
    ++sharedData;
    dataPresent=1;
    notify();
    System.out.print("Producer: Unlock shared data and flag\n");
    /* unlock occurs when leaving the synchronized method */
}
}

public class ATEST18 {
    public final static int NUMTHREADS = 2;
    public static theSharedData dataConditionEncapsulation = new theSharedData();

    static class theThread extends Thread {
        public void run() {
            int    retries=2;

            System.out.print("Consumer " + getName() + ": Entered\n");
            while (retries-- != 0) {
                dataConditionEncapsulation.get();
                /* Typically an application would process the data outside */
                /* the monitor (synchronized get method here)           */
            }
            System.out.print("Consumer " + getName() + ": All done\n");
        }
    }

    public static void main(String argv[]) {
        int    amountOfData = 4;
        theThread threads[] = new theThread[NUMTHREADS];
        System.out.print("Entered the testcase\n");

        System.out.print("Create/start the thread\n");
        for (int i=0; i < NUMTHREADS; ++i) {
threads[i] = new theThread();
            threads[i].start();
        }

        while (amountOfData-- != 0) {
            System.out.print("Producer: 'Finding data\n");
            try {
                Thread.sleep(3000);
            }
            catch (InterruptedException e) {
                System.out.print("sleep interrupted\n");
            }
            dataConditionEncapsulation.put();
        }

        System.out.print("Wait for the threads to complete\n");
        for(int i=0; i < NUMTHREADS; ++i) {
try {
            threads[i].join();
        }
        catch (InterruptedException e) {
            System.out.print("Join interrupted\n");
        }
    }
}
}

```



```

        System.out.print("Testcase completed\n");
        System.exit(0);
    }
}

```

Threads as synchronization primitives

Threads themselves can be used as synchronization primitives when one thread specifically waits for another thread to complete.

The waiting thread does not continue processing until the target thread has finished running all of its application code. Compared to other synchronization techniques, there is little cooperation in this synchronization mechanism.

A thread that is used as a synchronization primitive does not have the concept of an owner, such as in other synchronization techniques. A thread just waits for another to finish processing and end.

Related concepts

“End a thread” on page 16

When a thread has completed its processing, it takes an action to end itself and release system resources for use by other threads.

Space location locks

A space location lock puts a logical lock on any single byte of storage. The lock does not change the storage or effect your application’s access to the storage. The lock is a piece of information recorded by the system.

Space location locks provide cooperative locking similar to that provided by mutual exclusion (mutexes). However, space location locks differ from mutexes in several respects:

- You can use the space location lock directly on the data it is protecting. The space location lock does not require your application to create and maintain an additional object. Correct results in your application still depend on the fact that all threads that are accessing the data use the space location lock.
- Space location locks allow an application to coordinate the use of different locking request types. For example, more than one thread can use space location locks to acquire a shared lock on the same data.
- Due to the extra lock types that are provided by space location locks, the concept of an owner is slightly different than with mutexes. There can be multiple owners of a shared lock if each owner has successfully acquired the shared lock. For a thread to get an exclusive lock, all of the shared locks must be unlocked.
- Space location locks have different performance implications to your application than mutexes. A space location lock costs about 500 reduced instruction set computer (RISC) instructions to lock in a path without contention between other threads. A mutex costs about 50 RISC instructions in the same path. However, a space location lock has no creation or deletion costs associated with it, while a mutex costs approximately 1000 RISC instructions for creation or deletion.

Note: Java does not have the ability to directly use space location locks. Space location locks require the use of pointers.

Example: Space location locks in Pthread programs:

This example shows a Pthread program that is dynamically initializing an integer using the space location lock synchronization primitive.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
Filename: ATEST19.QCSRC
The output of this example is as follows:

```

```

Enter Testcase - LIBRARY/ATEST19
Hold Lock to prevent access to shared data
Create/start threads
Thread 00000000 00000025: Entered
Wait a bit until we are 'done' with the shared data
Thread 00000000 00000026: Entered
Thread 00000000 00000027: Entered
Unlock shared data
Wait for the threads to complete, and release their resources
Thread 00000000 00000025: Start critical section, holding lock
Thread 00000000 00000025: End critical section, release lock
Thread 00000000 00000026: Start critical section, holding lock
Thread 00000000 00000026: End critical section, release lock
Thread 00000000 00000027: Start critical section, holding lock
Thread 00000000 00000027: End critical section, release lock
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <mih/milckcom.h>      /* Lock types          */
#include <mih/locks1.h>       /* LOCKSL instruction */
#include <mih/unlocks1.h>     /* UNLOCKSL instruction */

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

#define NUMTHREADS 3
int sharedData=0;
int sharedData2=0;

void *theThread(void *parm)
{
    int rc;
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    locks1(&sharedData, _LENR_LOCK); /* Lock Exclusive, No Read */
    /****** Critical Section *****/
    printf("Thread %.8x %.8x: Start critical section, holding lock\n",
        pthread_getthreadid_np());
    /* Access to shared data goes here */
    ++sharedData; --sharedData2;
    printf("Thread %.8x %.8x: End critical section, release lock\n",
        pthread_getthreadid_np());
    unlocks1(&sharedData, _LENR_LOCK); /* Unlock Exclusive, No Read */
    /****** Critical Section *****/
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_t thread[NUMTHREADS];
    int rc=0;
    int i;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Hold Lock to prevent access to shared data\n");
    locks1(&sharedData, _LENR_LOCK); /* Lock Exclusive, No Read */

    printf("Create/start threads\n");
    for (i=0; i < NUMTHREADS; ++i) {

```

```

    rc = pthread_create(&thread[i], NULL, theThread, NULL);
    checkResults("pthread_create()\n", rc);
}

printf("Wait a bit until we are 'done' with the shared data\n");
sleep(3);
printf("Unlock shared data\n");
unlocksl(&sharedData, _LENR_LOCK); /* Unlock Exclusive, No Read */

printf("Wait for the threads to complete, and release their resources\n");
for (i=0; i < NUMTHREADS; ++i) {
    rc = pthread_join(thread[i], NULL);
    checkResults("pthread_join()\n", rc);
}

printf("Main completed\n");
return 0;
}

```

Related concepts

“One-time initialization and thread safety” on page 46

At times, you might want to defer the initialization of resources until a thread requires them.

However, your application might require that multiple threads use a certain resource, which requires you to initialize the resource only once in a threadsafe way.

Object locks

Object locks provide ways to acquire locks on specific system or application objects.

In some cases, the system acquires object locks on behalf of actions a user takes against certain objects. The system respects and enforces object locks for some actions.

You can acquire object locks such that the lock is effective only within the thread (thread-scoped) or is effective within the process (process-scoped). If two threads in the same process each try to acquire a process-scoped lock to a system object, that lock is satisfied for both threads. Neither thread prevents the other from acquiring the lock if they are in the same process.

If you are using object locks to protect access to an object from two threads within the same process, you should use object locks that are scoped to a thread. A thread-scoped object lock never conflicts with an object lock scoped to a process that is acquired by the same process.

Object locks allow an application to coordinate the use of different locking request types. More than one thread can acquire a shared but thread-scoped lock on the same system object. Your application can also acquire different types of object locks in a way that is similar to space locks. This allows more than one thread to acquire a thread-scoped shared lock on a single target.

Because extra lock types are provided by object locks, the concept of an owner is slightly different than it is with mutual exclusions (mutexes). There can be multiple owners of a shared, thread-scoped lock. If each owner has successfully acquired the shared thread-scoped lock, all of the shared locks must be unlocked for a thread to get an exclusive thread-scoped object lock.

Compare and Swap

You can use the Machine Interface’s (MI) Compare and Swap (CMPSWP) instruction to access data in a multithreaded program.

CMPSWP compares the value of a first compare operand to the value of a second compare operand. If they are equal, the swap operand is stored in the second compare operand’s location. If they are unequal, the second compare operand is stored into the first compare operand’s location.

When an equal comparison occurs, it is assured that no access by another CMPSWP instruction will occur at the second compare operand location between the moment that the second compare operand is fetched for comparison and the moment that the swap operand is stored at the second compare operand location.

When an unequal comparison occurs, no atomicity guarantees are made regarding the store to the first compare operand location and other CMPSWP instruction access. Thus only the second compare operand should be a variable shared for concurrent processing control.

The following code example for a C macro can be used to atomically increment or decrement an integer variable.

```
#ifndef __cmpswp_h
#include <mih/cmpswp.h>
#endif

#define ATOMICADD ( var, val, rc ) { \
    int aatemp1 = (var); \
    int aatemp2 = aatemp1 + val; \
    while( ! _CMPSWP( &aatemp1, &var, aatemp2 ) ) \
        aatemp2 = aatemp1 + val; \
    rc = aatemp2; \
}
```

In the code example, *var* is an integer to be incremented or decremented, *val* is an integer value to be added or subtracted from *var*, and *rc* is the resultant value.

One-time initialization and thread safety

At times, you might want to defer the initialization of resources until a thread requires them. However, your application might require that multiple threads use a certain resource, which requires you to initialize the resource only once in a threadsafe way.

There are several ways you can initialize a resource that is used multiple times in a threadsafe fashion. Most of these methods involve a Boolean value to allow the application to quickly determine whether the required initialization is completed. You must also use a synchronization technique in addition to the Boolean flag to ensure that the initialization completed.

Related concepts

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

“Common multithreaded programming errors” on page 53

Several programming errors often occur when writing multithreaded applications.

Related reference

“Example: Space location locks in Pthread programs” on page 43

This example shows a Pthread program that is dynamically initializing an integer using the space location lock synchronization primitive.

“Thread-specific data” on page 48

Typical applications that are not threaded use global storage.

Example: One-time initialization in Pthread programs

This example shows a Pthread program that is dynamically initializing an integer using the Pthread one time initialization support.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```
/*
Filename: ATEST20.QCSRC
The output of this example is as follows:
```

```

Enter Testcase - LIBRARY/ATEST20
Create/start threads
Wait for the threads to complete, and release their resources
Thread 00000000 00000007: Entered
Thread 00000000 00000000: INITIALIZE RESOURCE
Thread 00000000 00000007: The resource is 42
Thread 00000000 00000006: Entered
Thread 00000000 00000009: Entered
Thread 00000000 00000008: Entered
Thread 00000000 0000000a: Entered
Thread 00000000 00000006: The resource is 42
Thread 00000000 0000000a: The resource is 42
Thread 00000000 00000009: The resource is 42
Thread 00000000 00000008: The resource is 42
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

#define NUMTHREADS 5
pthread_once_t oneTimeInit = PTHREAD_ONCE_INIT;
int initialized = 0;
int resource = 0;

void initFunction(void)
{
    printf("Thread %.8x %.8x: INITIALIZE RESOURCE\n");
    resource = 42;
    /* Ensure that all initialization is complete and flushed */
    /* to storage before turning on this boolean flag */
    /* Perhaps call a function or register an exception */
    /* that causes an optimization boundary */
    initialized = 1;
}

void *theThread(void *parm)
{
    int rc;
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    if (!initialized) {
        rc = pthread_once(&oneTimeInit, initFunction);
        checkResults("pthread_once()\n", rc);
    }
    printf("Thread %.8x %.8x: The resource is %d\n",
        pthread_getthreadid_np(), resource);
    return NULL;
}

int main(int argc, char **argv)
{
    pthread_t thread[NUMTHREADS];
    int rc=0;
    int i;

    printf("Enter Testcase - %s\n", argv[0]);

    printf("Create/start threads\n");

```

```

for (i=0; i < NUMTHREADS; ++i) {
rc = pthread_create(&thread[i], NULL, theThread, NULL);
    checkResults("pthread_create()\n", rc);
}

printf("Wait for the threads to complete, and release their resources\n");
for (i=0; i < NUMTHREADS; ++i) {
rc = pthread_join(thread[i], NULL);
    checkResults("pthread_join()\n", rc);
}

printf("Main completed\n");
return 0;
}

```

Thread-specific data

Typical applications that are not threaded use global storage.

When changing the application or application services to run in a multithreaded application, you must use a synchronization technique to protect global storage from being changed by multiple threads at the same time. Thread-specific data allows a thread to maintain its own global storage that is hidden from the other threads.

Due to the design of the application, threads might not function correctly if they share the global storage of the application. If eliminating the global storage is not feasible, you should consider using thread-specific data.

Consider the example of a server that stores information about the client and the current transaction in global storage. This server is never able to share the client information in a multithreaded environment without significant redesign. The application can instead pass the client information from function to function instead of using the global client information.

However, the application can maintain the client and transaction information in thread-specific data more easily than it can be modified to eliminate the use of global storage. When each new thread is created, the thread uses a global identifier (or key) to create and store its thread-specific data. Each client (thread) then has unique but global client data.

In addition, some API sets provide a way for the system to automatically call a data destructor function that cleans up the thread-specific data when a thread ends.

Related concepts

“One-time initialization and thread safety” on page 46

At times, you might want to defer the initialization of resources until a thread requires them.

However, your application might require that multiple threads use a certain resource, which requires you to initialize the resource only once in a threadsafe way.

Example: Thread-specific data in Pthread programs

This example shows a Pthread program creating thread-specific data.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
Filename: ATEST22.QCSRC
The output of this example is as follows:
Enter Testcase - LIBRARY/ATEST22
Create/start threads
Wait for the threads to complete, and release their resources
Thread 00000000 00000036: Entered
Thread 00000000 00000036: foo(), threadSpecific data=0 2
Thread 00000000 00000036: bar(), threadSpecific data=0 2

```

```

Thread 00000000 00000036: Free data
Thread 00000000 00000037: Entered
Thread 00000000 00000037: foo(), threadSpecific data=1 4
Thread 00000000 00000037: bar(), threadSpecific data=1 4
Thread 00000000 00000037: Free data
Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

void foo(void); /* Functions that use the threadSpecific data */
void bar(void);
void dataDestructor(void *data);

#define checkResults(string, val) { \
    if (val) { \
        printf("Failed with %d at %s", val, string); \
        exit(1); \
    } \
}

typedef struct {
    int      threadSpecific1;
    int      threadSpecific2;
} threadSpecific_data_t;

#define          NUMTHREADS  2
pthread_key_t   threadSpecificKey;

void *theThread(void *parm)
{
    int          rc;
    threadSpecific_data_t *gData;
    printf("Thread %.8x %.8x: Entered\n", pthread_getthreadid_np());
    gData = (threadSpecific_data_t *)parm;
    rc = pthread_setspecific(threadSpecificKey, gData);
    checkResults("pthread_setspecific()\n", rc);
    foo();
    return NULL;
}

void foo() {
    threadSpecific_data_t *gData = pthread_getspecific(threadSpecificKey);
    printf("Thread %.8x %.8x: foo(), threadSpecific data=%d %d\n",
        pthread_getthreadid_np(), gData->threadSpecific1, gData->threadSpecific2);
    bar();
}

void bar() {
    threadSpecific_data_t *gData = pthread_getspecific(threadSpecificKey);
    printf("Thread %.8x %.8x: bar(), threadSpecific data=%d %d\n",
        pthread_getthreadid_np(), gData->threadSpecific1, gData->threadSpecific2);
    return;
}

void dataDestructor(void *data) {
    printf("Thread %.8x %.8x: Free data\n", pthread_getthreadid_np());
    pthread_setspecific(threadSpecificKey, NULL);
    free(data);
}

int main(int argc, char **argv)

```

```

{
pthread_t          thread[NUMTHREADS];
int                rc=0;
int                i;
threadSpecific_data_t *gData;

printf("Enter Testcase - %s\n", argv[0]);
rc = pthread_key_create(&threadSpecificKey, dataDestructor);
checkResults("pthread_key_create()\n", rc);

printf("Create/start threads\n");
for (i=0; i < NUMTHREADS; ++i) {
    /* Create per-thread threadSpecific data and pass it to the thread */
    gData = (threadSpecific_data_t *)malloc(sizeof(threadSpecific_data_t));
    gData->threadSpecific1 = i;
    gData->threadSpecific2 = (i+1)*2;
    rc = pthread_create(&thread[i], NULL, theThread, gData);
    checkResults("pthread_create()\n", rc);
}

printf("Wait for the threads to complete, and release their resources\n");
for (i=0; i < NUMTHREADS; ++i) {
    rc = pthread_join(thread[i], NULL);
    checkResults("pthread_join()\n", rc);
}

pthread_key_delete(threadSpecificKey);
printf("Main completed\n");
return 0;
}

```

Example: Thread-specific data in Java programs

This example shows a Java program creating thread-specific data. Because a Java thread is created on an object, the use of thread-specific data is transparent. Java is a language that performs garbage collection. Note the lack of data destructors or other cleanup action.

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

```

/*
FileName: ATEST22.java
The output of this example is as follows:
Entered the testcase
Create/start threads
Thread Thread-1: Entered
Thread Thread-1: foo(), threadSpecific data=0 2
Thread Thread-1: bar(), threadSpecific data=0 2
Wait for the threads to complete
Thread Thread-2: Entered
Thread Thread-2: foo(), threadSpecific data=1 4
Thread Thread-2: bar(), threadSpecific data=1 4
Testcase completed
*/
import java.lang.*;

public class ATEST22 {
    public final static int NUMTHREADS = 2;

    static class theThread extends Thread {
        int                threadSpecific1;
        int                threadSpecific2;

        public theThread(int i, int i2) {
            threadSpecific1 = i;
            threadSpecific2 = i2;
        }
    }
}

```



```

    }
    public void run() {
        System.out.print("Thread " + getName() +
            ": Entered\n");
        foo();
        return;
    }
    void foo() {
        System.out.print("Thread " + getName() +
            ": foo(), threadSpecific data=" +
            String.valueOf(threadSpecific1) + " " +
            String.valueOf(threadSpecific2) + "\n");
        bar();
    }
    void bar() {
        System.out.print("Thread " + getName() +
            ": bar(), threadSpecific data=" +
            String.valueOf(threadSpecific1) + " " +
            String.valueOf(threadSpecific2) + "\n");
    }
}

public static void main(String argv[]) {
    System.out.print("Entered the testcase\n");

    System.out.print("Create/start threads\n");
    theThread threads[] = new theThread[NUMTHREADS];
    for (int i=0; i < NUMTHREADS; ++i) {
        threads[i] = new theThread(i, (i+1)*2);
        threads[i].start();
    }

    System.out.print("Wait for the threads to complete\n");
    for (int i=0; i < NUMTHREADS; ++i) {
        try {
            threads[i].join();
        }
        catch (InterruptedException e) {
            System.out.print("Join interrupted\n");
        }
    }
    System.out.print("Testcase completed\n");
    System.exit(0);
}
}

```

Function calls that are not thread safe

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

To illustrate the alternatives, consider the example of a program that calls API `foo()`. Because function `foo()` is listed as not being thread safe, you need to find a safe way to call it. Two common options are using a global mutual exclusion (mutex) or using a separate job to run the function that is not thread safe.

Related concepts

“Thread safety” on page 27

A function is threadsafe if you can start it simultaneously in multiple threads within the same process.

A function is threadsafe if and only if all the functions it calls are also threadsafe.

“Synchronization techniques among threads” on page 31

When you create code that is threadsafe but still benefits from sharing data or resources between threads, the most important aspect of programming becomes the ability to synchronize threads.

“One-time initialization and thread safety” on page 46

At times, you might want to defer the initialization of resources until a thread requires them. However, your application might require that multiple threads use a certain resource, which requires you to initialize the resource only once in a threadsafe way.

“Common multithreaded programming errors” on page 53

Several programming errors often occur when writing multithreaded applications.

Related reference

“CL commands and thread safety” on page 29

The Integrated Language Environment (ILE) CL run time and compiler-generated code are threadsafe. Original program model (OPM) CL programs are not threadsafe.

“Threads considerations for ILE COBOL and RPG language” on page 57

You can create an Integrated Language Environment (ILE) COBOL or ILE RPG module that will run safely in a multithreaded environment by serializing access to the module.

Use global mutexes to run functions that are not threadsafe

One alternative you should consider when you need to call a function that is not threadsafe is using a global mutual exclusion (mutex) to run these functions.

You might try locking a mutex that you call the FOO MUTEX whenever you call foo(). This works if you know everything about the internal parts of foo(), but for general operating system functions, this is still not a completely safe solution.

For example, API foo() is not threadsafe because it calls API bar(), which calls threadUnsafeFoo(). The threadUnsafeFoo() function uses certain storage and control blocks in an unsafe way. In this example, those storage and control blocks are called DATA1.

Because the API threadUnsafeFoo() is unsafe, any application or system service that uses foo() is not threadsafe because using it with multiple threads might result in damaged data or undefined results.

Your application also uses a threadsafe API or system service that is called wiffle(). Wiffle() calls waffle(), which accesses storage and control blocks DATA1 in a threadsafe manner. (That is waffle() and a group of other APIs use an internal DATA1 MUTEX).

Your application does not know the underlying DATA1 connection between foo() and wiffle() system services. Your application therefore does not lock the FOO MUTEX before calling wiffle(). When a call to foo() (holding the FOO MUTEX) occurs at the same time as a call to wiffle(), the application’s use of the not threadsafe function foo() causes DATA1 and whatever it represents to be damaged.

As complex as this scenario is, consider how complex resolving failures is when you do not know the internal details of all the functions involved.

Do not try to make operating system services or functions threadsafe by using your own serialization.

Use separate jobs to run functions that are not threadsafe

There are several threadsafe mechanisms to submit a new job to complete the processing you need.

- If your application uses CL commands that are not threadsafe, you can use the system API Qp0zSystem(). This API is similar to the C system() function; however, it starts a new process before running the CL command. It also returns some information about the results of the CL command that you ran. For more details about Qp0zSystem(), see the System API Programming Reference.
- If your application calls APIs or programs that are not thread safe, you might use the spawn() API to start a new job. If you use the spawn() API, your application must decide which part of the application environment gets duplicated into the child. The spawn() API allows the child process to inherit open IFS files, sockets, or other resources from the parent. For details about spawn(), see the System API Programming Reference.

- Your application might frequently use multiple functions that are not thread safe. In this case, you should use one of the previously mentioned mechanisms to start a new job. That new job can function as a server, running the code that is not threadsafe when requested by your application. Your application can use message queues, data queues, or perhaps semaphores to communicate with your server.

When using any of these separate job mechanisms, you need to be aware of the following problems involved with using a different job to complete some of your application processing:

- **Input/output considerations:**
The server job cannot perform normal I/O without conflicting with the application I/O processing. The application I/O processing can affect file offsets or locks that are maintained on system objects. Attempts at I/O can conflict between the jobs.
- **Parameter passing:**
Passing pointers or other types of complex parameters to the functions that are not threadsafe might not be easy to accomplish. That function runs in a separate job. You need to solve the problems involved with passing complex data to that function.
- **Returning function calls:**
The results from the function that is not threadsafe might be more complex than the simple pass/fail type of information that is provided by some of the mechanisms described above. This is similar to the parameter passing issue described above.
- **Job attributes:**
You might have additional complexity to manage when trying to duplicate your application's environment in the server job. For example, if you started your application as user ALICE, and you started the server job as user BOB, the application behavior is not correct.

Common multithreaded programming errors

Several programming errors often occur when writing multithreaded applications.

Related concepts

“One-time initialization and thread safety” on page 46

At times, you might want to defer the initialization of resources until a thread requires them.

However, your application might require that multiple threads use a certain resource, which requires you to initialize the resource only once in a threadsafe way.

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

“Debugging and servicing of multithreaded jobs” on page 58

Use the concepts and techniques that are described here to learn about debugging and servicing multithreaded jobs:

Related information

Troubleshooting pthread errors

Calling functions that are not threadsafe

The most common programming error when writing a threaded application is the use of APIs or system services that are not thread safe.

An application needs to be aware of each API that it calls and whether the provider classifies it as thread safe. If the API or system-provided service is thread safe, it must use only other threadsafe APIs or system services in its implementation.

This is especially problematic when your application calls user-written code that is outside of your control. You cannot validate this code for thread safety. If the user code is not threadsafe and you call it within your application's own process context, you might damage the application data, or the application might halt.

Related reference

"Threads considerations for C language" on page 56

You must evaluate existing C applications for thread safety before calling them in a multithreaded job. If your C program is not threadsafe, techniques are available for calling programs that are not threadsafe from multithreaded jobs.

Thread creation not allowed failure

i5/OS does not allow every process on the system to create threads at every time while running.

You can specify special parameters when you create a job. These parameters can indicate that the job should allow multiple threads.

For example, the `spawn()` application programming interface (API) has a multithreaded flag that can be specified in the inheritance parameter. You can use other ways to submit i5/OS jobs that allow you to specify that the new job should be allowed to create threads. Some job types allow the use of a job description specifying that the job that is started using the job description should be allowed to start threads. To do this, use the **Allow Multithread (ALWMLTTHD)** parameter on the Create Job Description (CRTJOBDD) or Change Job Description (CHGJOBDD) commands.

If you attempt to create a thread in a job that is not capable of starting threads, thread creation fails. See your API or language specific documentation for details on how the failure is manifested.

The same failure recurs if your application is running the destructors for C++ static objects or C/C++ program termination routines. Application code cannot create threads when the job is ending.

Activation group ending

The i5/OS Integrated Language Environment (ILE) program model uses activation groups as a way to encapsulate resources for an application program within a job.

When multiple threads exist in the processes that possibly use the activation group, the system cannot end that activation group in a predictable and safe way. To solve this problem, the system changes the behavior of ending an activation group in a multithreaded job.

If a secondary thread in a multithreaded application performs an action that ends an activation group (for example, C functions `exit()` or `abort()`) or fails to prevent an activation group from ending, the system takes action to end the process at that time. If the initial thread in an multithreaded application performs an action that ends an activation group or fails to prevent an activation group from ending, the system ends the activation group but does not end the process.

A typical example of this occurs when a current i5/OS application is altered to take advantage of multithreading. The current i5/OS application probably uses multiple program objects. Unlike other platforms, i5/OS allows you to call the programs within the same process context as the currently running application code.

The default activation group attribute for a program is `*NEW`. Calling a program with a default activation of `*NEW` in a multithreaded job ends both the activation group and the process when the program ends. If the job is to remain active after the program ends, the program should be changed to use the `*DEFAULT` or a named activation group.

Mixing thread models

Do not mix Pthreads APIs with other thread management APIs that might be provided by the system.

For example, you should not use Java or the IBM Open Class libraries threads implementations in the same thread or process as Pthreads. More importantly, do not attempt to manipulate a thread from one threads implementation with the API of another. Unpredictable results might occur.

For example, you can manipulate the priority of a thread by using Pthread interfaces and non-Pthread interfaces. If you do so, the priority is always set correctly. However, the priority returned from the Pthread interface `pthread_getschedparam()` is correct only if setting the priority was always done using either the `pthread_setschedparam()` interface or some other interface, but not both. If you instead use multiple interfaces to set the priority of the thread, `pthread_getschedparam()` always returns the priority that was set by the last use of the `pthread_setschedparam()` interface.

Similarly, you can end a Java thread using the `pthread_exit()` API if you are running application code in a native method. However, using `pthread_exit()` to end the Java thread can have unexpected repercussions. These can include bypassing some of the Java environment thread processing or perhaps ending the Java thread in a way that your Java application does not expect and cannot handle.

Commit operations in multithreaded programs

Database transactions in i5/OS are scoped to the job or the activation group.

If your multithreaded application is working on multiple database transactions in multiple threads simultaneously, it is possible that a commit operation in one thread also commits activity done by another thread.

For example, an application has a thread that is working on a database transaction for client1 and another thread working on a database transaction for client2. The thread that is processing for client1 completes its processing and commits the changes. This commit operation also commits all the changes made for client2. Your application must be aware of the in-flight transactions that are in progress.

Related reference

“Database considerations for multithreaded programming” on page 5

You should consider these items when using databases in multithreaded programs.

Database record I/O and thread safety

You can use the I/O feedback area of a database file to communicate results of I/O operations to the record I/O user. A typical application might have problems with thread safety because of the nature of the feedback area.

When you perform an I/O operation, the support of the run time and of the database ensures that the I/O operation is threadsafe. When the I/O is complete, any locks that the run time holds are released and control is given back to the application.

It is the application’s responsibility to serialize access when examining the I/O feedback area so that another thread does not use it simultaneously. COBOL and RPG use the feedback area on every I/O operation, so if you do I/O to the same shared file with different languages, you should serialize access to the file even when you are not apparently using the feedback area.

For example, Thread 1 is using file A for record I/O operations. The system stores information about those operations in the feedback area for file A. After the I/O operation for Thread 1 completes, Thread 1 manipulates the feedback area by examining fields in the feedback area. If it does not protect the feedback area when Thread 2 uses file A for record I/O operations, the system uses the same feedback area. Thread 1 may get inconsistent results because Thread 2 is using the feedback area at the same time. This occurs when sharing a file is conducted by the use of the file pointer or file descriptor number. It is not a problem if the file is opened in each thread.

You should use a synchronization technique to protect the feedback area so that other application code or the system does not change it when it is being accessed.

Related reference

“Database considerations for multithreaded programming” on page 5
You should consider these items when using databases in multithreaded programs.

Language access and threads

Learn how different languages support threads on i5/OS. This information can help you evaluate how threads can be implemented in your own application.

The concepts that are described in this section pertain to all programming languages. To determine how each language enables these concepts, refer to the Language topic in the information center for the specific language.

Threads considerations for Java language

You can take advantage of i5/OS kernel threads using the `java.lang.Thread` class. Java threads operate on top of the i5/OS kernel threads model. Each Java thread is one of many tasks that runs in the process.

You can do all of the activities that are listed in the Threads Management section.

The Java virtual machine (JVM) always creates several threads to perform services such as Java garbage collection. The system uses these threads; applications should not use them.

You can use native methods to access system functions that are not available in Java. Native methods are not *PGM objects. They are procedures that are exported from Integrated Language Environment (ILE) service programs (*SRVPGM). These native methods always run in processes that are multithreaded so they must be threadsafe. The ILE COBOL, RPG IV, CL, C and C++ compilers are threadsafe.

Note: Not all standard C and C++ functions are threadsafe. Refer to the C and C++ topic in the information center.

When it is necessary to call an ILE program (*PGM) object, use `java.lang.Runtime.exec()` to start another process in which the program can run.



Use `exit()` and `abort()` with care. These functions end the application, including the process and all the threads that run in the process.

Related concepts

“Examples: Threads” on page 67
These examples are used throughout this topic.

Threads considerations for C language

You must evaluate existing C applications for thread safety before calling them in a multithreaded job. If your C program is not threadsafe, techniques are available for calling programs that are not threadsafe from multithreaded jobs.

Not all C library functions are threadsafe. Before calling your existing C applications in a multithread-capable job, refer to the *WebSphere® Development Studio: ILE C/C++ Programmer's Guide*, SC09-2712 PDF  and *WebSphere Development Studio: C/C++ Language Reference*, SC09-4815 PDF  to determine whether all of your functions are threadsafe.

When using programs that are written in C, use the following actions:

- Re-creation of Integrated Language Environment (ILE) C applications:
Compile and bind all existing ILE C applications with `TGTRLS(*CURRENT)` before you call them in a multithreaded job.

- Elimination of *NEW activation groups:
You should not use *NEW activation groups in multithreaded applications.

Note: ACTGRP(*NEW) is the default on CRTPGM and CRTBNDC commands.

- Calling ILE C *PGM objects:

If you need to call an ILE C *PGM object that has an activation group of *NEW, either start another process to run the second program or create the second program specifying a named activation group.

Related reference

“Calling functions that are not threadsafe” on page 53

The most common programming error when writing a threaded application is the use of APIs or system services that are not thread safe.

Threads considerations for C++ language

The C++ runtime functions new, delete, try, catch, and throw are threadsafe.

Not all C++ library functions are threadsafe. Before calling your existing C applications in a multithread-capable job, refer to the *WebSphere Development Studio: ILE C/C++ Programmer's Guide*,

SC09-2712 PDF  and *WebSphere Development Studio: C/C++ Language Reference*, SC09-4815 PDF  to determine whether all of your functions are threadsafe.

Threads considerations for ILE COBOL and RPG language

You can create an Integrated Language Environment (ILE) COBOL or ILE RPG module that will run safely in a multithreaded environment by serializing access to the module.

You do this by specifying THREAD (SERIALIZE) on the PROCESS statement for COBOL or THREAD (*SERIALIZE) on the Control specification for RPG. When you serialize a module, only one thread can run any procedure in that module at one time. For example, consider a module that has procedures P1 and P2. If one thread is running procedure P1, no other thread can run either procedure P1 or P2 until the first thread has finished running P1. Even when a module is serialized, the COBOL or RPG programmer must ensure that global storage and heap storage are accessed in a threadsafe way. Even if an RPG or COBOL procedure apparently only uses automatic storage, RPG and COBOL use static storage control blocks in every procedure. Therefore, you must always specify THREAD (*SERIALIZE) when using ILE RPG or COBOL in a multithreaded environment.

Related concepts

“Function calls that are not thread safe” on page 51

Your multithreaded application at times requires access to functions or system services that are not thread safe. There are few completely safe alternatives for calling these functions.

Threads considerations for OPM language

Original program model (OPM) programs are not threadsafe.

You should migrate OPM programs to Integrated Language Environment (ILE) and make them threadsafe before a multithreaded application calls them. User-written Java methods should not call OPM programs. When it is necessary to call an OPM program in a multithreaded application, you should start another process to run the OPM program.

Related concepts

“Thread program models” on page 2

There are different models for creating multithread programs.

Debugging and servicing of multithreaded jobs

Use the concepts and techniques that are described here to learn about debugging and servicing multithreaded jobs:

The concepts that are described in this section pertain to all programming languages. To determine how each language enables these concepts, refer to the Language topic in the information center for the specific language.

Related concepts

“Common multithreaded programming errors” on page 53

Several programming errors often occur when writing multithreaded applications.

Commands that report thread-related data

Most of the commands used to service jobs were not changed to support multithreaded processes. Therefore, the existing commands will continue to operate against the job and not individual threads within the job.

The following commands were enhanced to report thread-related data:

Dump Job (DMPJOB) command:

The Dump Job command now dumps all threads within a job. The thread-related data is available through use of the JOBTHD parameter on the command. The following example shows how to obtain a multithreaded job dump that contains the thread-related data:

```
STRSRVJOB JOB(000000/USER/JOBNAME)
DMPJOB PGM(*NONE) JOBARA(*NONE) ADROBJ(*NO) JOBTHD(*THDSTK)
ENDSRVJOB
```

Start Trace (STRTRC) command:

The Start Trace command allows you either to trace all threads within a multithreaded job or to specify up to 20 specific threads to be traced in a multithreaded job. The thread identifier is included in each trace record to indicate the thread that caused the record to be entered into the log. The following example shows how to obtain a trace for a multithreaded job:

```
STRTRC SSNID(MYSSNID) JOB((000000/USERNAME/JOBNAME (*ALL)))
... tracing the job
ENDTRC SSNID(MYSSNID) DTALIB(MYLIB) PRTRC(*YES)
```

The following example shows how to obtain a trace for specified threads in a multithreaded job:

```
STRTRC SSNID(MYSSNID) JOB((000000/USERNAME/JOBNAME (00000001 00000002 00000003)))
... tracing the job
ENDTRC SSNID(MYSSNID) DTALIB(MYLIB) PRTRC(*YES)
```

First Failure Data Capture (FFDC) function:

FFDC is a function that you can use in your program, service program, or module to report a problem for an authorized program analysis report (APAR). FFDC logs the problem, builds a symptom string, and collects problem analysis data.

FFDC is not fully functional when used in a multithreaded program. When it is called in a multithreaded program, FFDC provides partial support that includes:

- Collecting data item information and storing this information in the QPSRVDMP spool file.
- Storage of the point of failure, symptom string, and the detecting and suspected program information in the QPSRVDMP spool file. The job log also contains this information.
- Starting the Dump Job (DMPJOB) command.

FFDC support for object dumping, problem entry creation, or data collection for problem determination is not provided within a multithreaded job.

Flight recorders

A useful way to debug multithreaded applications is to write data to a flight recorder. A flight recorder is a file, output buffer, or some other object where trace information is written so that problems in the application can be tracked.

Entries to and exits from a function are typical information that is traced in a flight recorder. Parameters that are passed to functions, major changes in control flow, and error conditions are often tracked as well.

The Pthread library provides a way for your application to trace problems. Tracing allows you to cut optional trace points, turn the recorder on or off, and recompile your application so that all of the tracing code is removed.

You can use different levels of tracing. If your application wants to honor the trace levels, it is the application's responsibility to cue trace points at the appropriate trace levels, or manage the trace level. The Pthread library provides APIs, macros, and trace level variables to assist you.

For Pthread tracing, an error-level tracing displays only those trace points that have error-level severity. An informational-level tracing traces all error-level trace points in addition to the informational trace points. A verbose-level trace point traces all levels. Each trace point automatically includes the thread ID, a timestamp of millisecond granularity, and the trace data.

The CL commands that enable, display, and work with the tracing are part of i5/OS.

The tracing buffers for your tracepoints are created as user space objects in the QUSRSYS library. The trace buffers are named QP0Zxxxxxx, in which xxxxxx is the six-digit job number of the job that performed the tracing.

The following APIs relate to tracing and are detailed in the UNIX-Type APIs guide:

- Qp0zUprintf - print formatted trace data
- Qp0zDump - dump formatted hexadecimal data
- Qp0zDumpStack - dump the call stack of the calling thread
- Qp0zDumpTargetStack - dump the call stack of the target thread
- Qp0zLprintf - print formatted job log message

The following CL commands that allow you to manipulate tracing:

- DMPUSRTRC - dump the contents of a specified job's trace
- CHGUSRTRC - change attributes (size, wrapping, clear) of a specified job's trace
- DLTUSRTRC - delete the persistent trace object that is associated with a job's trace

Example: Sample flight recorder output from a Pthread program

This example shows a Pthread program that is using the flight recorder or tracing interfaces that are provided by the system.

Note: By using the code examples, you agree to the terms of the "Code license and disclaimer information" on page 68.

```
/*  
Filename: ATEST23.QCSRC  
Use CL command DMPUSRTRC to output the following tracing  
information that this example traces.
```

This information is put into a file QTEMP/QAP0ZDMP or to standard output.

The trace records are indented and labeled based on thread id, and millisecond timestamp of the time the tracepoint was cut.

The following trace output occurs when the optional parameter 'PTHREAD_TRACING' is NOT specified when calling this program.

If the optional parameter 'PTHREAD_TRACING' is specified, many more tracepoints describing pthread library processing will occur.

Use the Pthread library tracepoints to debug incorrect calls to the Pthreads library from your application.

Trace output -----

User Trace Dump for job 096932/MYLIB/PTHREADT. Size: 300K, Wrapped 0 times.

--- 11/06/1998 11:06:57 ---

```
0000000D:133520 Create/start a thread
0000000D:293104 Wait for the thread to complete, and release their resources
0000000E:294072 Thread Entered
0000000E:294272 DB51A4C80A:001CD0 L:0008 Global Data
0000000E:294416 DB51A4C80A:001CD0 00000000 00000002 *.....*
0000000E:294496 foo(), threadSpecific data=0 2
0000000E:294568 bar(), threadSpecific data=0 2
0000000E:294624 bar(): This is an error tracepoint
0000000E:294680 Stack Dump For Current Thread
0000000E:294736 Stack: This thread's stack at time of error in bar()
0000000E:333872 Stack: Library / Program Module Stmt Procedure
0000000E:367488 Stack: QSYS / QLESPI QLECRTTH 774 : LE_Create_Thread2__FP12crtth_parm_t
0000000E:371704 Stack: QSYS / QP0WPTH R QP0WPTH R 1008 : pthread_create_part2
0000000E:371872 Stack: MYLIB / PTHREAD T PTHREAD T 19 : theThread__FPv
0000000E:371944 Stack: MYLIB / PTHREAD T PTHREAD T 29 : foo__Fv
0000000E:372016 Stack: MYLIB / PTHREAD T PTHREAD T 46 : bar__Fv
0000000E:372104 Stack: QSYS / QP0ZCPA QP0ZDBG 87 : Qp0zDumpStack
0000000E:379248 Stack: QSYS / QP0ZSCP A QP0ZSCP A 276 : Qp0zSUDumpStack
0000000E:379400 Stack: QSYS / QP0ZSCP A QP0ZSCP A 287 : Qp0zSUDumpTargetStack
0000000E:379440 Stack: Completed
0000000E:379560 foo(): This is an error tracepoint
0000000E:379656 dataDestructor: Free data
0000000D:413816 Create/start a thread
0000000D:414408 Wait for the thread to complete, and release their resources
0000000F:415672 Thread Entered
0000000F:415872 DB51A4C80A:001CD0 L:0008 Global Data
0000000F:416024 DB51A4C80A:001CD0 00000001 00000004 *.....*
0000000F:416104 foo(), threadSpecific data=1 4
0000000F:416176 bar(), threadSpecific data=1 4
0000000F:416232 bar(): This is an error tracepoint
0000000F:416288 Stack Dump For Current Thread
0000000F:416344 Stack: This thread's stack at time of error in bar()
0000000F:416552 Stack: Library / Program Module Stmt Procedure
0000000F:416696 Stack: QSYS / QLESPI QLECRTTH 774 : LE_Create_Thread2__FP12crtth_parm_t
0000000F:416784 Stack: QSYS / QP0WPTH R QP0WPTH R 1008 : pthread_create_part2
0000000F:416872 Stack: MYLIB / PTHREAD T PTHREAD T 19 : theThread__FPv
0000000F:416952 Stack: MYLIB / PTHREAD T PTHREAD T 29 : foo__Fv
0000000F:531432 Stack: MYLIB / PTHREAD T PTHREAD T 46 : bar__Fv
0000000F:531544 Stack: QSYS / QP0ZCPA QP0ZDBG 87 : Qp0zDumpStack
0000000F:531632 Stack: QSYS / QP0ZSCP A QP0ZSCP A 276 : Qp0zSUDumpStack
0000000F:531704 Stack: QSYS / QP0ZSCP A QP0ZSCP A 287 : Qp0zSUDumpTargetStack
0000000F:531744 Stack: Completed
0000000F:531856 foo(): This is an error tracepoint
0000000F:531952 dataDestructor: Free data
0000000D:532528 Main completed
*/
#define _MULTI_THREADED
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <qp0ztrc.h>
#define checkResults(string, val) { \
```

```

if (val) {
    printf("Failed with %d at %s", val, string); \
    exit(1); \
} \
}

typedef struct {
    int      threadSpecific1;
    int      threadSpecific2;
} threadSpecific_data_t;

#define          NUMTHREADS  2
pthread_key_t    threadSpecificKey;

void foo(void);
void bar(void);
void dataDestructor(void *);

void *theThread(void *parm) {
    int      rc;
    threadSpecific_data_t *gData;
    PTHREAD_TRACE_NP({
        Qp0zUprintf("Thread Entered\n");
        Qp0zDump("Global Data", parm, sizeof(threadSpecific_data_t));,
        PTHREAD_TRACE_INFO_NP);
    gData = (threadSpecific_data_t *)parm;
    rc = pthread_setspecific(threadSpecificKey, gData);
    checkResults("pthread_setspecific()\n", rc);
    foo();
    return NULL;
}

void foo() {
    threadSpecific_data_t *gData =
        (threadSpecific_data_t *)pthread_getspecific(threadSpecificKey);
    PTHREAD_TRACE_NP(Qp0zUprintf("foo()", threadSpecific data=%d %d\n",
        gData->threadSpecific1, gData->threadSpecific2);,
        PTHREAD_TRACE_INFO_NP);
    bar();
    PTHREAD_TRACE_NP(Qp0zUprintf("foo(): This is an error tracepoint\n");,
        PTHREAD_TRACE_ERROR_NP);
}

void bar() {
    threadSpecific_data_t *gData =
        (threadSpecific_data_t *)pthread_getspecific(threadSpecificKey);
    PTHREAD_TRACE_NP(Qp0zUprintf("bar()", threadSpecific data=%d %d\n",
        gData->threadSpecific1, gData->threadSpecific2);,
        PTHREAD_TRACE_INFO_NP);
    PTHREAD_TRACE_NP(Qp0zUprintf("bar(): This is an error tracepoint\n");,
        Qp0zDumpStack("This thread's stack at time of error in bar()");,
        PTHREAD_TRACE_ERROR_NP);
    return;
}

void dataDestructor(void *data) {
    PTHREAD_TRACE_NP(Qp0zUprintf("dataDestructor: Free data\n");,
        PTHREAD_TRACE_INFO_NP);
    pthread_setspecific(threadSpecificKey, NULL); free(data);
    /* If doing verbose tracing we will even write a message to the job log */
    PTHREAD_TRACE_NP(Qp0zLprintf("Free'd the thread specific data\n");,
        PTHREAD_TRACE_VERBOSE_NP);
}

/* Call this testcase with an optional parameter 'PTHREAD_TRACING' */
/* If the PTHREAD_TRACING parameter is specified, then the */
/* Pthread tracing environment variable will be set, and the */

```

```

/* pthread tracing will be re initialized from its previous value. */
/* NOTE: We set the trace level to informational, tracepoints cut */
/*      using PTHREAD_TRACE_NP at a VERBOSE level will NOT show up*/
int main(int argc, char **argv) {
    pthread_t          thread[NUMTHREADS];
    int                rc=0;
    int                i;
    threadSpecific_data_t *gData;
    char                buffer[50];

    PTHREAD_TRACE_NP(Qp0zUprintf("Enter Testcase - %s\n", argv[0]),,
                     PTHREAD_TRACE_INFO_NP);
    if (argc == 2 && !strcmp("PTHREAD_TRACING", argv[1])) {
        /* Turn on internal pthread function tracing support          */
        /* Or, use ADDENVVAR, CHGENVVAR CL commands to set this envvar*/
        sprintf(buffer, "QIBM_PTHREAD_TRACE_LEVEL=%d", PTHREAD_TRACE_INFO_NP);
        putenv(buffer);
        /* Refresh the Pthreads internal tracing with the environment */
        /* variables value.                                           */
        pthread_trace_init_np();
    }
    else {
        /* Trace only our application, not the Pthread code          */
        Qp0wTraceLevel = PTHREAD_TRACE_INFO_NP;
    }

    rc = pthread_key_create(&threadSpecificKey, dataDestructor);
    checkResults("pthread_key_create()\n", rc);

    for (i=0; i < NUMTHREADS; ++i) {
        /* Create per-thread threadSpecific data and pass it to the thread */
        gData = (threadSpecific_data_t *)malloc(sizeof(threadSpecific_data_t));
        gData->threadSpecific1 = i;
        gData->threadSpecific2 = (i+1)*2;
        rc = pthread_create( &thread[i], NULL, theThread, gData);
        checkResults("pthread_create()\n", rc);
        PTHREAD_TRACE_NP(Qp0zUprintf("Wait for the thread to complete, "
                                     "and release their resources\n"),,
                        PTHREAD_TRACE_INFO_NP);
        rc = pthread_join(thread[i], NULL);
        checkResults("pthread_join()\n", rc);
    }

    pthread_key_delete(threadSpecificKey);
    PTHREAD_TRACE_NP(Qp0zUprintf("Main completed\n"),,
                    PTHREAD_TRACE_INFO_NP);
    return 0;
}

```

Options to view thread information

The Display Job (DSPJOB), Work with Job (WRKJOB), and Work with Active Jobs (WRKACTJOB) commands allow you to display and work with threads associated with an i5/OS job.

Through each of these commands, you can select an option that allows you to display or work with the threads in the job. You can use the Work with Threads display to view the following information for the job:

- List of threads:

This display shows all of the threads that are currently associated with the job. The first thread in the list is the initial thread in the process. An eight-digit number (Thread) identifies threads by their identifier. This list changes depending on the thread activity in the job. Other information about this display includes the thread's status of active or waiting, total CPU usage, total auxiliary storage I/O counts, and thread run priority.

- Thread call stack option:

This option displays the call stack of any thread. In some conditions, typically when the thread is running an instruction that cannot be interrupted, the call stack cannot be displayed. In these cases, a message indicates that no stack information is available is displayed.

- Thread mutual exclusions (mutexes) option:

This option allows you to see all mutexes associated with a specific thread. This includes mutexes that are held and the mutex for which the thread might be waiting. If the specified thread has no mutexes that are associated with it, the Job or thread has no mutexes message is displayed.

- Thread locks option:

This option allows you see all the thread-scoped object locks held by the thread. It also allows you to see all pending process-scoped locks and thread-scoped locks on which the the thread is waiting. If the specified thread has no object locks associated with it, the Thread has no locks message is displayed.

- Hold thread option:

This option allows you to temporarily suspend the running of a specific thread. This option is useful if you suspect that a thread might be looping or causing some other system problem. You must use the Hold thread option in conjunction with the Release thread option. Unlike Hold Job (HLDJOB), repeated Hold thread requests are cumulative. To resume the running of a held thread, you must issue the equivalent number of Release thread requests.

- Release thread option:

This option is used to resume the running of a thread that has been suspended.

- End thread option:

This option allows you to end a specific thread. In general, you should not use of this option because it can cause unpredictable results. This option requires *SERVICE special authority.

The Release Job (RLSJOB), Hold Job (HLDJOB), End Job (ENDJOB), and End Job Abnormal (ENDJOBABN) commands affect all threads within a multithreaded job. No commands are planned to provide the equivalent thread-level support.

Multithreaded job debugging

The spawn() API provides a mechanism to allow you to start a debugging session before actually calling the multithreaded program to be debugged.

Setting the QIBM_CHILD_JOB_SNDINQMSG environment variable to 1 controls this capability. Refer to the usage notes for the spawn() API in the System API Reference, for details about the use of this environment variable.



An example SPAWN command is available for your use and modification as part of i5/OS option 7, the i5/OS Example Tools Library, QUSRTOOL. Member TP0ZINFO in the file QATTINFO in the QUSRTOOL library contains information about how to create the SPAWN CL command.

You can also simplify the process of starting a job that runs the multithreaded program and the debugging session by creating a command (such as the SPAWN command) that performs the necessary steps. The steps are as follows:

- Signing on to a display station session
- Starting a job to run the multithreaded program
- Using the Start Service Job (STRSRVJOB) command to service the job running the multithreaded program
- Calling the Start Debug (STRDBG) command, adding programs to debug, and setting breakpoints
- Notifying the servicing job when the thread hits a breakpoint so that it stops the thread
- Stopping all threads with the debugger support
- Issuing valid debug commands from the debug screen that is displayed
- Resuming the thread that hit the breakpoint and then all other threads

- Repeating the above cycle until debugging is complete
- Calling the End Debug (ENDDBG) command

You can find additional information about thread debugging capabilities in the following topics:

- APIs
- SPAWN CL command, QUSRTOOL example
- *WebSphere Development Studio: ILE C/C++ Programmer's Guide, SC09-2712* PDF 
- *ILE Concepts, SC41-5606* PDF 

Areas to test for multithreaded applications

Testing is key to the process of verifying the correctness of a multithreaded program.

You should consider the following key concepts when testing a multithreaded program:

- Multiple instances:
Test your multithreaded program by having multiple instances of the program active at the same time. If your application allows the number of threads to vary, configure each instance of the program with a different number of threads.
- Vary system workload:
Test your multithreaded program by running it repeatedly with a different mix of applications running. The interaction of different applications might reveal timing problems or race conditions.
- Stress environments:
Environments running stressful workload can reveal contention, timing, and performance problems.
- Different hardware models:
Whenever possible, run your multithreaded program on different hardware models with varying workload and stress levels. Different hardware models, especially multiprocessor systems, reveal a variety of problems. If you are porting an application from another platform, verify that your application produces the same result on both platforms.

Testing is only one consideration for validating the correctness of a multithreaded program. Code inspections are critical and often the only way to determine potential problems. When inspecting the code for a multithreaded program, you need to continually ask the question, "If the code is interrupted at this point, what potential problems can occur?" Often, knowing the potential sources of problems helps you avoid them. Common problems are as follows:

- Hardware-related problems:
It is typically sufficient to test a single-threaded program on one hardware model and expect that it will behave identically on different hardware models. Unlike with single-threaded programs, you cannot have the same expectation with a multithreaded program that runs on a hardware platform that supports kernel threads. On these platforms, each thread runs in a separately dispatched task. Depending on processor speed, main memory sizes, storage capacity, and other hardware characteristics, timing problems or race conditions might result when the multithreaded programs are called on different hardware. Multiprocessor systems further increase the likelihood of discovering potential problems. On multiprocessor systems, two different threads can be running the same sequence of code at the same time.
- Java virtual machine implementation problems:
A problem for Java application developers is the implementation of the Java virtual machine (JVM). On some platforms, the JVM is single-threaded. On i5/OS, the JVM is multithreaded. Similar problems might occur with a Java application as with an application from another platform that supports user threads.
- Threads model problems:

If you are porting an application from another platform, you need to know the threads model that the other platform supported. If the platform supported a user threads model, you might encounter problems with the application on i5/OS because it supports a kernel threads model. A key difference between the two models is that the user threads model uses cooperative scheduling and the kernel threads model uses preemptive scheduling. With a user threads model, only one thread in the application can be active at a given time. With a kernel threads model, the machine determines which threads are eligible to run. Race conditions, resource contention, and other problems might occur with kernel threads because the application writer did not consider these potential problems when using user threads.

Performance considerations in multithreaded applications

There are several performance considerations for multithreaded jobs on i5/OS.

The concepts that are described here pertain to all programming languages. For details about how each language enables a concept, refer to the Language topic in the information center for that specific language.

Multithreaded server recommendations

When you write a typical server to take advantage of threads, a common design is to have a single listener thread waiting for client requests and multiple individual worker threads to perform the client's requested operations.

Creating threads should not use very many resources. However, because some servers require a faster response time to clients, some server application programs maintain a pool of worker threads that are waiting for work. They do this to avoid creating new threads.

Typically, the worker threads use some synchronization primitive to wait for client processing requests. Instead of creating a new thread to process each client request, the listener thread queues the client request and signals the waiting worker threads. The signal sometimes uses variables.

A server application is commonly considered trusted with the data that it serves to clients. Because the server is running multithreaded applications, you must consider some issues concerning the activities it performs:

- You should not call user application code from a multithreaded server. To run user application code safely from a multithreaded server, the user application code must follow the same strict rules that the original multithreaded server did. These rules concern the actions that it can take and the application programming interfaces (APIs) that it can call
- As you should with any other part of your application, you must evaluate the processing that is required to fulfill the client request for its thread safety.
- Processing on behalf of the client might affect process-level resources of the server in a way that is not wanted for the server. For example, changing the coded character set identifier (CCSID) so that data representation is the same as that of the client also affects other threads in the job. CCSID is a job resource.
- A server can change the security information (user profile and group profile) of a worker thread to make it become the client that is being served. However, when the server does this, you need to consider what resources the threads share. The worker thread has access to all the already opened job level resources that more privileged users in the same job might have created or opened.

Job and thread priorities

An i5/OS thread competes with threads throughout the system for scheduling resources in addition to competing with other threads in the same job.

The system schedules processing resources by using a delay cost scheduler that is based on several delay cost curves (priority ranges).

On i5/OS, numerically lower priority values indicate higher priority with regard to scheduling. Adding its thread priority adjustment value to the job's priority specifies the priority of a thread. The default priority for a thread is no change from the process priority or a thread priority adjustment value of zero.

You can directly affect the application performance by assigning different thread priority adjustment values to the threads in your application.

Contention among threads

Contention occurs when one thread has to wait for another thread to finish using a resource.

Contention problems can occur if your application uses too few mutual exclusions (mutexes) to protect access to a large number of resources. A large number of threads that share a small number of resources can also cause contention between threads in your application.

Contention between threads over resources can cause context switches and paging. To reduce contention within your application, you should hold locks for the shortest amount of time and try to prevent a single lock from being used for two different or unrelated shared resources.

Threads that poll or spin to wait for resources prevent scaling. This form of contention can drastically affect the performance of your application. Polling or spinning can also adversely affect other threads or jobs, degrading system performance. Use condition variables, semaphores, mutexes, or other synchronization primitives so that threads never need to poll or spin to wait for resources to become available.

Effects of storage pool sizes on threaded applications

The storage pool size specified for a subsystem affects the performance and number of threads you can create.

If thread creation or processing is slow or fails consistently with an out-of-memory error, you might not have enough resources available in the storage pool to run all of your application threads in addition to the other jobs that are using the same storage pool. Increasing the storage pool size might eliminate these problems.

You can examine the storage pool sizes by using the Work with System Status (WRKSYSSTS) command. If you have too many active threads or threads that use too many system resources, you will see numerous page faults for the storage pools in which applications are running. Increasing the storage pool size might reduce the number of page faults.

Activity levels of storage pools

The activity level of a storage pool refers to the number of active threads within that storage pool.

A single job with 500 threads takes up the same number of activity level slots as 500 jobs with a single thread. If the activity level is too low for the number of threads and jobs that are active, your threads are paged out of main storage and marked as ineligible for a short time. This can drastically affect the performance of your application.

Performance and threaded applications

Job-level performance counters are updated by all the threads in a job.

The presence of multiple active threads can affect the accuracy of both general system counters and performance monitor specific transaction boundary counters. Data loss might occur as there is no automatic synchronization for these counters.

The initial thread performance information is a combination of thread and job-scoped data. Derived information that involves both thread and job-scoped data is not valid unless you total the thread-scoped data across all threads.

Examples: Threads

These examples are used throughout this topic.

Use the following as examples for your programs:

Note: By using the code examples, you agree to the terms of the “Code license and disclaimer information” on page 68.

Pthread examples:

- “Example: Set a thread attribute in a Pthread program” on page 12
- “Example: Start a thread in a Pthread program” on page 14
- “Example: End a thread in a Pthread program” on page 16
- “Example: Cancel a thread in a Pthread program” on page 19
- “Example: Wait for threads in a Pthread program” on page 24
- “Example: Use mutexes in Pthread programs” on page 33
- “Example: Use semaphores in Pthread programs to protect shared data” on page 36
- “Example: Use condition variables in Pthread programs” on page 38
- “Example: Space location locks in Pthread programs” on page 43
- “Example: One-time initialization in Pthread programs” on page 46
- “Example: Thread-specific data in Pthread programs” on page 48
- “Example: Sample flight recorder output from a Pthread program” on page 59
- “Example: Work with local SQL databases in multithreaded Pthread programs” on page 7

Java examples:

- “Example: Set a thread attribute in Java” on page 13
- “Example: Start a thread using Java” on page 15
- “Example: End a thread using Java” on page 17
- “Example: Cancel a thread using Java” on page 20
- “Example: Suspend a thread using Java” on page 22
- “Example: Wait for threads using Java” on page 25
- “Example: Use mutexes in Java” on page 34
- “Example: Use condition variables in Java programs” on page 40
- “Example: Thread-specific data in Java programs” on page 50

Related reference




“Threads considerations for Java language” on page 56

You can take advantage of i5/OS kernel threads using the `java.lang.Thread` class. Java threads operate on top of the i5/OS kernel threads model. Each Java thread is one of many tasks that runs in the process.

Related information for multithreaded applications

Listed here are the manuals (in PDF format), Web sites, and information center topics that relate to the multithreaded applications topic. You can view or print any of the PDFs.

Manuals

- *WebSphere Development Studio: ILE C/C++ Programmer's Guide, SC09-2712* PDF 
- *WebSphere Development Studio: C/C++ Language Reference, SC09-4815* PDF 
- *ILE Concepts, SC41-5606* PDF 

Web site

The Sun Java tutorial 

Other information


- APIs
- Language

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- | eServer
- | e(logo)server
- | i5/OS
- | IBM
- | IBM (logo)
- | Integrated Language Environment
- | Intelligent Printer Data Stream
- | IPDS
- | iSeries
- | WebSphere

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