PARALLEL // PROGRAMMING

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PARALLELISM

- parallel programming
  - to perform a number of tasks simultaneously
    - these can be calculations, or data transfer or…
- In Unix, many programs run in at the same time handling various tasks
  - we like multitasking…
  - we don’t like waiting…

SIMPLEST WAY: FORK()

- Each process has a process ID called PID.
- After a fork() call,
  - there will be a second process with another PID which we call the child.
  - The first process, will also continue to exist and to execute commands, we call it the mother.

FORK() EXAMPLE

```
#include <stdio.h>      // printf, stderr, fprintf
#include <sys/types.h> // pid_t
#include <unistd.h>     // _exit, fork
#include <stdlib.h>     // exit
#include <errno.h>      // errno

int main(void)
{
   pid_t  pid;
   pid = fork();

   if (pid == -1) {
      fprintf(stderr, "can't fork, error %d\n",
errno);
      exit(EXIT_FAILURE);
   }

   if (pid == 0) {
      /* Child process:
       * If fork() returns 0, it is the child
process.
       */
      int j;
      for (j = 0; j < 15; j++) {
         printf("child: %d\n", j);
         sleep(1);
      }
      _exit(0);  /* Note that we do not use
exit() */
   } // end of child
   else
   {

      /* If fork() returns a positive number, we
are in the parent process
       * (the fork return value is the PID of the
newly created child process)
       */
      int i;
      for (i = 0; i < 10; i++)
      {
         printf("parent: %d\n", i);
         sleep(1);
      }
      exit(0);
   }// end of parent

   return 0;
}
```

```
USER   PID  %CPU %MEM      VSZ    RSS   TT  STAT STARTED      TIME COMMAND
ngu  46379   0.0  0.0  2432744    204 s006  S+    3:35PM   0:00.00 ./a.out
ngu  46378   0.0  0.0  2432744    484 s006  S+    3:35PM   0:00.00 ./a.out
```

WHY NOT TO FORK

- fork() system call is the easiest way of branching out to do 2 tasks concurrently. BUT
  - it creates a separate address space such that the child process has an exact copy of all the memory segments of the parent process.
  - This is "heavy" in terms of memory footprint
  - Forking is a "slow" operation.

A BETTER WAY

- **Threads**
  - smallest “executable” task
  - small footprint, quick to launch
  - contrary to processes, threads share all resources
    - memory (program code and global data)
    - open file/socket descriptors
    - signal handlers and signal dispositions
    - working environment (current directory, user ID, etc.)
  - included in posix standards
- Basic functions: start, stop, wait,...

WHY SHOULD I LEARN?

- These days CPU frequency seems to have been saturated around 3GHz.
- We now see an increase of #cores/cpu
  - We need to learn parallel programming to get the maximum performance from our hardware
  - parallel programming also makes our software more efficient, even on a single core.
- We want to be able to share LOTS of data and perform complicated tasks
  - real life examples from HEP experiments DAQ

POSIX THREADS

pthread_create

- you have the man pages to remember the usage
  - man pthread_create

```
#include <pthread.h>

int  pthread_create(pthread_t *restrict thread,
                    const pthread_attr_t *restrict attr,
                    void *(*start_routine)(void *),
                    void *restrict arg);
```

- good luck with the short description...
  - learn (suffer) once, put in a wrapper library, use your library afterwards.
  - we will develop such a library during this lecture.

A WORKING EXAMPLE .

```
#include <errno.h>
#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include <unistd.h>             /* POSIX et al */
#include <fcntl.h>
#include <signal.h>
#include <pthread.h>

#define TH_FAIL 1
#define TH_OK   0

void test_thread(char *arg)
{

     fprintf(stdout, "test_thread: errno=%d\n", errno);
     while (1) {
          sleep(1);
          fprintf(stdout, "%s\n", arg);
     }
}
```

includes

simple definitions

simple function to print the argument

- Our wrapper function: `launch_thread`
  - send : function to execute, argument to the function
  - receive : status, tid

```
int main(void)
{
     int prio;
     int status;

     char *data;
     long th_handle1, th_handle2, th_handle3;

     data = "GREEN";
     status = launch_thread(&th_handle1, test_thread, data);

     data = "orange";
     status = launch_thread(&th_handle2, test_thread, data);

    sleep(10);
    printf("test DONE !\n");

     exit(0);
}
```

A WORKING EXAMPLE ..

```
int launch_thread(long *th_handle,
                  void *start_func, void *param)
{
     pthread_t tid;
     pthread_attr_t attr;

#ifdef DEBUG
     if (param != NULL) {
          printf("sys_open_thread: arg is %d \n", *((int *) param));
     }
#endif

     pthread_attr_init(&attr);
     if (pthread_create(&tid, &attr, start_func, param) == -1) {
          printf("sys_open_thread: pthread_create error.\n");
          return (TH_FAIL);
     }
     *th_handle = (long int)tid;
     return (TH_OK);
}
```

ins & outs

create thread

return TID

- compile and link with -lpthread

```
gcc ex1.c -o ex1b -lpthread
```

ex1.c

THREADS IN C++11

c++11 implementation has inserted lots of functionality into the std library…

/usr/local/bin/g++ -std=c++11 ex1.cpp -o ex1

simpler !

```
#include <thread>
#include <chrono>
#include <iostream>

void test_thread(std::string arg)
{
     std::cout<< "test_thread: errno="<< errno <<std::endl;
     std::chrono::milliseconds duration( 1000 );
     while (1) {
          std::cout << arg << std::endl;
          std::this_thread::sleep_for( duration );
     }
}

//---------------------------------
int main(void)
{
     int prio;

     std::thread::id th_handle1, th_handle2, th_handle3;

     std::thread t1(test_thread, "Green");
     th_handle1=t1.get_id();

     std::thread t2(test_thread, "Orange");
     th_handle2=t2.get_id();

     std::chrono::milliseconds duration( 10000 );
     std::this_thread::sleep_for( duration );

     std::cout << "test DONE !" <<std::endl;
     exit(0);
}
```

includes

simple function to print the argument

create thread

get TID

ex1 .cpp

TAKE AWAY FROM EX1

- How to run multiple tasks in parallel.
- How to hide complex function calls in to a simple wrapper library.
- How to compile and execute a threaded program in Unix.
  - c with posix threads
  - c++11

GET THE ID

- Each thread has a unique ID#: TID
  - a TID can be obtained after creation.
  - a thread's own TID is obtained with
    - `pthread_self()`
    - `std::this_thread::get_id()`
- TIDs can be cast to a long unsigned int. In a thread, one can do
  - `printf("This is TID: %lu:\n",(unsigned long)pthread_self());`
    - could be useful in debugging...

TOOLS

- ps: process list, exists in all Unix variants
  - options to list processes including thread IDs, check the man page for your *nix.
    - linux, try: ps -eLf
- pstree: linux specific
- top: sort processes, exists in all Unix variants
  - Linux: H to turn on/off display of Threads

TID

```
UID        PID  PPID   LWP  C NLWP
fizikci    549   541   549  0    1
fizikci    560     1   560  0    1
fizikci    561     1   561  0    1
fizikci    568     1   568  0    1
fizikci    573     1   573  0    1
fizikci    583   549   583  0    2
fizikci    583   549   588  0    2
fizikci    587   583   587  0    1
```

```
[fizikci@hpfbu ~]$ pstree
init─┬─Terminal─┬─bash
     │          ├─bash───pstree
     │          ├─gnome-pty-helpe
     │          └─{Terminal}
     ├─3*[VBoxClient───{VBoxClient}]
     ├─VBoxClient
     ├─6*[agetty]
     ├─crond
     ├─dbus-daemon
     ├─dbus-launch
     ├─dhcpcd
     ├─gpg-agent
     ├─gvfs-fuse-daemo───3*[{gvfs-fuse-daemo}]
     ├─gvfsd
     ├─gvfsd-trash
     ├─slim─┬─X───2*[{X}]
     │      └─sh───xfce4-session─┬─Thunar
     │                           ├─xfce4-panel─┬─panel-6-systray
     │                           │             └─{xfce4-panel}
     │                           ├─xfdesktop───{xfdesktop}
     │                           ├─xfwm4
     │                           └─{xfce4-session}
     ├─sshd
     ├─syslog-ng───syslog-ng
     ├─udevd───2*[udevd]
     ├─xfce4-settings-
     ├─xfconfd
     └─xfsettingsd
```

TERMINATE A THREAD

- if the executed function exits or finishes, the thread exits as well.
  - pthread_exit terminates the current thread.
  - pthread_cancel nicely terminates any thread, it requires a TID to work on.

```
int exit_thread(long my_th_handler)
{
     if (my_th_handler == 0) {
          pthread_exit(0);      /* If self, just exit */
     }
     if (pthread_cancel((pthread_t)my_th_handler) != 0) {
          printf("exit_thread: cancel error\n");
          return (TH_FAIL);
     }
#ifdef DEBUG
     printf("killed! %d \n", (my_th_handler));
#endif
     return (TH_OK);
}
```

ex2a.c

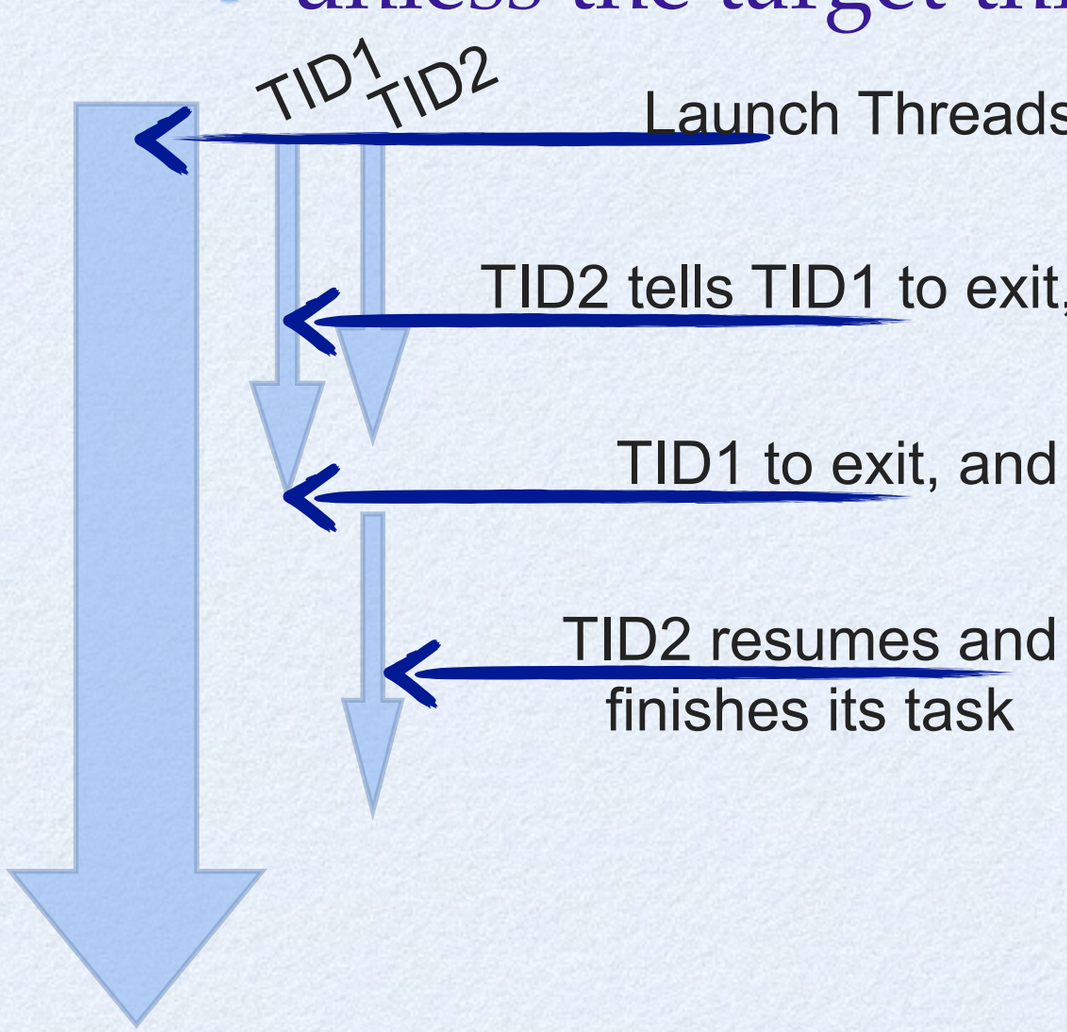
Not possible to brutally kill a thread in c++11.

TAKE AWAY FROM EX2A

- Don't assume that you really killed a thread even if the system call returns success.
  - it will terminate the function whenever it is convenient.
- We have very fast computers, few microseconds means long time.
  - you will not have exact control if you do not wait for the actual termination.

WAITING FOR THE OTHER

- The pthread_join() function suspends execution of the calling thread until the target thread exits,
  - unless the target thread has already terminated.




```
int waitfor_thread(long my_th_handler)
{
     int i, status;

     if (pthread_join((pthread_t)my_th_handler, (void **) &status) != 0) {
          printf("sys_waitfor_thread: join error\n");
          return (TH_FAIL);
     }
     return (TH_OK);

}
```

TO WAIT OR NOT ?

addition to main

```
dummy=0;

while (dummy<1E2) {
 if ( dummy==0) {
   printf ("Killing a TH.\n");
   status = exit_thread(th_handle2);
   printf ("Sent kill signal.\n");
   status = waitfor_thread(th_handle2);
   printf ("Killed.\n");
 }
 printf (" main active\n");
 usleep(10);
 dummy++;
}
```

- If we don't use the wait function, the "dead" thread will be still active for a while:
  - If not used, see that "orange" printed after "Killed."
  - If used, there is no such printout.

ex2b.c

```
GREEN
orange
orange
Killing a TH.
Sent kill signal.
orange
GREEN
Killed.
 main active
GREEN
 main active
GREEN
```

```
Killing a TH.
Sent kill signal.
Killed.
 main active
GREEN
GREEN
 main active
orange
GREEN
GREEN
GREEN
 main active
GREEN
```

MEANWHILE IN C++11

```
#include <thread>
#include <chrono>
#include <iostream>

void test_thread(std::string arg)
{
     std::cout<< "test_thread: errno="<< errno <<std::endl;
     std::chrono::milliseconds duration( 1000 );
     std::cout<<std::this_thread::get_id()<<std::endl;
     int count=0;
     while (count < 5 ) {
          std::cout << arg << std::endl;
          std::this_thread::sleep_for( duration );
          if (arg=="Orange") {
            count++;
          }
     }
}

//------------------------------
int main(void)
{
     std::thread::id th_handle1, th_handle2, th_handle3;

     std::thread *t1 = new std::thread(test_thread, "Green");
     th_handle1=t1->get_id();

     std::thread *t2= new std::thread(test_thread, "Orange");
     th_handle2=t2->get_id();

     std::chrono::milliseconds duration( 4000 );
     std::this_thread::sleep_for( duration );

     std::cout << "joining t2 to wait it finish. suspending main." <<std::endl;
     t2->join();
     delete(t2);
     std::cout << "t2 is finished. t1 continues and main is resumed." <<std::endl;

     std::this_thread::sleep_for( duration );
     std::cout << "test DONE !" <<std::endl;
     exit(0);
}
```

- C++11 doesn't allow any outside influence:
  - kill, cancel, exit … functions don't exist.
- C++11 allows only 2 possibilities
  - detach() : make the thread independent.
  - join() : wait for the thread to finish.

a thread should know when to exit

to wait for a thread to finish gracefully

TAKE AWAY FROM EX2B

	+	-	Real life example
with wait function	Precision in task executions	•Becomes priority vs all other commands •Time consuming	ATM machine controls
without wait function	Allows other functions to continue in parallel	No accurate timing in execution	User interaction (e.g. display help)

FIGHTING FOR CPU CYCLES

scheduling

- For different processes
  - Cooperative multitasking
    - Processes voluntarily cede time to one another
  - Preemptive multitasking - for realtime applications *(your smart phone!)*
    - Operating system guarantees that each process gets a "slice" of time for execution and handling of external events (I/O) such as interrupts
- For different threads
  - SCHED_FIFO - first in first out
    - runs until either it is blocked by an I/O request, it is preempted by a higher priority process, or it calls sched_yield.
  - SCHED_RR - round robin
    - same as above, except that each process is only allowed to run for a maximum time quantum.
  - SCHED_OTHER (linux, not in bsd)
    - Linux default, for processes without any realtime requirements.

Let them know: signal

pthread_kill

- Life is Asynchronous.
  - Things can happen at any time, a good software has to take into account such events.
- In computing, we use signals to mark such events.
  - for example, we could pause and continue a thread at our will.

PS: Don't let _kill fool you, it simply means send a signal.

```
int suspend_thread(long my_th_handler)
{
     if (pthread_kill(my_th_handler, SUSPEND_SIGNAL) == -1) {
          printf("suspend_thread: kill error\n");
          return (TH_FAIL);
     }
     return (TH_OK);
}
```

HANDLING THE SIGNALS

- A library should be able to
  - receive a signal
  - do something about it

```
int thread_signal_handler(void)
{
     struct sigaction th_act;
     th_act.sa_handler = thread_signal_action;
     th_act.sa_flags= 0;
     if (sigaction(SUSPEND_SIGNAL, &th_act, (struct sigaction *) NULL)) {
          printf("sigaction: cant catch SUSPEND_SIGNAL\n");
          return (TH_FAIL);
     }
     pthread_setcancelstate(PTHREAD_CANCEL_ENABLE, NULL);
     pthread_setcanceltype(PTHREAD_CANCEL_ASYNCHRONOUS, NULL);

     return TH_OK;
}
```

```
static void thread_signal_action(int signo)
{
     printf ("We got signal: %i\n",signo);
     if (signo == SUSPEND_SIGNAL) { sleep (1000000);}
     return;
}
```

Poor man's suspend.
We will revisit this.

```
void test_thread(char *arg)
{
     thread_signal_handler();
     fprintf(stdout, "test_thread: errno=%d\n", errno);
     while (1) {
          usleep(10000);
          fprintf(stdout, "%s\n", arg);
     }
}
```

executed function should call the signal handler

TESTING

```
dummy=0;

printf ("suspending TH2...\n");
suspend_thread(th_handle2);

sleep(1);
printf("test DONE !\n");
exit(0);
```

- modify the main to add the new function

```
GREEN
orange
GREEN
orange
GREEN
orange
GREEN
orange
GREEN
orange
suspending TH2...
We got signal: 4
GREEN
GREEN
GREEN
GREEN
GREEN
GREEN
GREEN
GREEN
GREEN
```

no more orange !

ex3
.c

C++11 VERSION

```
#include <thread>
#include <chrono>
#include <iostream>
#include <csignal>

static int signaled = 0;

void sighandler(int sig) {
  signaled = 1;
  std::cout << "signaled.\n";
}

void test_thread(std::string arg)
{
     std::signal(SIGINT, sighandler);

     std::cout<< "test_thread: errno="<< errno <<std::endl;
     std::chrono::milliseconds duration( 1000 );
     std::cout<<std::this_thread::get_id()<<std::endl;
     int count=0;
     while (count == 0 ) {
          std::cout << arg << std::endl;
          std::this_thread::sleep_for( duration );
          if (arg=="Orange" && signaled) count=1;
     }
}
//--------------------------------
int main(void)
{
     std::thread::id th_handle1, th_handle2, th_handle3;

     std::thread *t1 = new std::thread(test_thread, "Green");
     th_handle1=t1->get_id();

     std::thread *t2= new std::thread(test_thread, "Orange");
     th_handle2=t2->get_id();

     std::chrono::milliseconds duration( 4000 );
     std::this_thread::sleep_for( duration );

     std::cout << "ask t2 to finish. suspending main." <<std::endl;
     std::raise (SIGINT);
     t2->join();
     delete(t2);
     std::cout << "t2 gone. t1 continues; main resumed." <<std::endl;


     std::this_thread::sleep_for( duration );
     std::cout << "test DONE !" <<std::endl;
     exit(0);
}
```

signal handler

activate signal handler

act on the signal result

ex3
.cpp

send the signal

no more orange !

```
0x104cf2000
0x104d75000
Green
Orange
OrangeGreen

Orange
Green
OrangeGreen

ask t2 to finish. suspending main.
signaled.
Green
t2 gone. t1 continues; main resumed.
Green
Green
Green
test DONE !
```

TAKE AWAY FROM EX3

- Signals are very useful to work in async mode.
- with pthreads,
  - we can send 1 signal to 1 TID at a time
  - there is a way for “broadcasting”, we’ll see how to do it later.
- with c++11 threads,
  - all threads receive the signal at the same time, up to the programmer to arrange the behavior.

ALWAYS USE PROTECTION

- *problem*: as the resources are shared, a variable can be modified by multiple threads

```
int aninteger=0;

void test_thread(char *arg)
{
     fprintf(stdout, "test_thread: errno=%d\n", errno);
     while (1) {
          usleep(1e4);
          fprintf(stdout, "%s and i=%i\n", arg, aninteger);
          if (strcmp(arg,"GREEN") ) {aninteger++;} else {aninteger--;}
     }
}
```

```
GREEN and i=0
orange and i=-1
GREEN and i=0
orange and i=-1
GREEN and i=0
orange and i=-1
test DONE !
An integer=0
```

run2

```
orange and i=-2
GREEN and i=-2
orange and i=-2
GREEN and i=-1
GREEN and i=-2
orange and i=-2
GREEN and i=-2
orange and i=-2
test DONE !
An integer=-2
```

run1

- different runs, different results —>

```
orange and i=1
GREEN and i=2
orange and i=1
GREEN and i=2
orange and i=1
GREEN and i=2
orange and i=1
test DONE !
An integer=2
```

run3

- *solution*: use MUTual EXclusion as protection.

CREATE AND LOCK

- There are 2 calls to create a mutex
  - `pthread_mutexattr_init ( pthread_mutexattr_t *attr);`
  - `pthread_mutex_init (pthread_mutex_t *mutex, const pthread_mutexattr_t *attr)`
- There are 2 calls to lock /unlock a mutex
  - `pthread_mutex_lock ( pthread_mutex_t *mutex);  // blocking`
  - `pthread_mutex_unlock ( pthread_mutex_t *mutex);`

```
void test_thread(char *arg)
{
     while (1) {
          printf ("This is %s, WILL wait...\n",arg);
          if (pthread_mutex_lock(&sys_th_mut) != 0) {
                    printf("sys_th_action 1: mutex_lock error\n");
          }
          if (strcmp(arg,"GREEN")==0 ) {
           aninteger++;
           usleep(1e6);
           printf ("This is %s, increasing\n",arg);
          } else { // this is what orange does
           printf ("This is %s, decreasing\n",arg);
           aninteger--;
           usleep(1); // orange will run much much faster...
          }
          printf ("This is %s, waiting OVER... and i=%i\n",arg, aninteger);
          if (pthread_mutex_unlock(&sys_th_mut) != 0) { // both will unlock
                    printf("sys_th_action 4: mutex_unlock");
          }
     }
}
```

locking call, if the mutex is free lock will be rapidly achieved, if not, the function call will wait until the mutex becomes available.

increase the common variable for GREEN and decrease for orange, except use different sleep values….

unlock the mutex, free it for the next usage.

OUTPUT

```
gokhans-macbook-pro:isotdaq2013 ngu$ ./ex5b
This is GREEN, WILL wait...
This is orange, WILL wait...
This is GREEN, increasing
This is GREEN, waiting OVER... and i=1
This is GREEN, WILL wait...
This is orange, decreasing
This is orange, waiting OVER... and i=0
This is orange, WILL wait...
This is GREEN, increasing
This is GREEN, waiting OVER... and i=1
This is GREEN, WILL wait...
This is orange, decreasing
This is orange, waiting OVER... and i=0
This is orange, WILL wait...
This is GREEN, increasing
This is GREEN, waiting OVER... and i=1
This is GREEN, WILL wait...
This is orange, decreasing
This is orange, waiting OVER... and i=0
This is orange, WILL wait...
test DONE !
An integer=1
```

- although orange is much much faster, we see same number of GREEN and orange calls.
  - This is nice, and expected: lock call waits for the MUTEX to be available.

ex4
.c

- one should destroy a mutex when it is not needed
  - pthread_mutex_destroy(*mutex)

IN C++11

```
#include <thread>
#include <chrono>
#include <iostream>
#include <csignal>
#include <mutex>

static int signaled = 0;
int aninteger=0;
std::mutex mylock;

void sighandler(int sig) {
  signaled = 1;
  std::cout << "signaled.\n";
}
void test_thread(std::string arg)
{
     std::signal(SIGINT, sighandler);

     std::cout<< "test_thread: errno="<< errno <<std::endl;
     std::chrono::milliseconds duration( 100 );
     std::cout<<std::this_thread::get_id()<<std::endl;
     int count=0;
     while (count == 0 ) {
          std::cout << arg << std::endl;
          std::this_thread::sleep_for( duration );
          if (arg=="Orange" && signaled) count=1;
          mylock.lock();
          if (arg=="Green") {aninteger++;} else {aninteger--;}
          mylock.unlock();
     }
}
//--------------------------------
int main(void)
{
     std::thread::id th_handle1, th_handle2, th_handle3;

     std::thread *t1 = new std::thread(test_thread, "Green");
     th_handle1=t1->get_id();

     std::thread *t2= new std::thread(test_thread, "Orange");
     th_handle2=t2->get_id();

     std::chrono::milliseconds duration( 4000 );
     std::this_thread::sleep_for( duration );

     std::cout << "ask t2 to finish. suspending main." <<std::endl;
     std::raise (SIGINT);
     t2->join();
     delete(t2);
     std::cout << "t2 gone. t1 continues; main resumed." <<std::endl;

     std::this_thread::sleep_for( duration );
     std::cout << "test DONE !" <<std::endl;
     std::cout << "An integer="<< aninteger << std::endl;
     exit(0);
}
```

define the mutex

locking call, if the mutex is free lock will be rapidly achieved, if not, the function call will wait until the mutex becomes available.

unlock the mutex, free it for the next usage.

TAKE AWAY FROM EX4

- Use a MUTEX when you need
  - to limit access to a particular data / counter etc...
  - to make a thread wait something to happen without polling on a condition
- polling is bad,
  - waste of cpu cycles

CONDITION VARIABLES .

- These provide another way for synchronization
  - mutexes control access to data
  - condition variables control actual value of data
- Why we need condition variables ?
  - these provide a blocking function, at low cpu usage
  - otherwise, one would have to poll continuously
- Note
  - a condition variable also needs a mutex

CONDITION VARIABLES ..

- two new variable types
  - `pthread_cond_t th_cond;`
  - `pthread_condattr_t th_cond_attr;`

condition variable and its attributes

- Five function calls
  - `pthread_condattr_init (*cond_attr);`
  - `pthread_cond_init(*cond, *cond_attr);`
  - `pthread_cond_broadcast (*cond);`
  - `pthread_cond_wait(*cond, *mutex);`
  - `pthread_cond_destroy(*cond);`

initialize the attributes

initialize the variable

publish the variable

blocking wait call

remove when done

LIBRARY IMPROVEMENTS

- Lets use the condition variables and blocking calls to implement a suspend-resume function
  - each thread has to have its own mutex & cond_var.

```
#define TH_FAIL 1
#define TH_OK   0
#define SUSPEND_SIGNAL  SIGILL
#define MAX_THREAD 10

pthread_mutex_t sys_th_mut[MAX_THREAD];
pthread_mutexattr_t sys_th_mut_attr;
pthread_cond_t sys_th_cond[MAX_THREAD];
pthread_condattr_t sys_th_cond_attr;
pthread_t thread_id[MAX_THREAD];

int th_global_num = -1;
```

we need to monitor the #of active threads in launch and exit

  - thread_launch: initialize cond_vars & mutexes
  - the signal action: incorporate cond_vars & mutexes
  - need resume_thread function
  - waitfor_thread: incorporate cond_vars & mutexes

```
int launch_thread(long *th_handle,
                  void *start_func, void *param)
{
     pthread_t tid;
     pthread_attr_t attr;
#ifdef DEBUG
     if (param != NULL) {
          printf("launch_thread: arg is %d \n", *((int *) param));
     }
#endif
     th_global_num++;
     if (th_global_num == MAX_THREAD) {
          printf("sys_open_thread: Maximum Thread Limit");
          return (TH_FAIL);
     }

     pthread_attr_init(&attr);
     if (pthread_create(&tid, &attr, start_func, param) == -1) {
          printf("open_thread: pthread_create error.\n");
          return (TH_FAIL);
     }
     *th_handle = (long int)tid;
     thread_id[th_global_num] = tid;
     if (pthread_mutexattr_init(&sys_th_mut_attr) == -1) {
          printf("sys_open_thread: mutexattr_init error");
          return (TH_FAIL);
     }
     if (pthread_mutex_init(&sys_th_mut[th_global_num], &sys_th_mut_attr) == -1) {
          printf("sys_open_thread: mutex_init error");
          return (TH_FAIL);
     }
     if (pthread_condattr_init(&sys_th_cond_attr) == -1) {
          printf("sys_open_thread: condattr_init error");
          return (TH_FAIL);
     }
     if (pthread_cond_init(&sys_th_cond[th_global_num], &sys_th_cond_attr) == -1) {
          printf("sys_open_thread: cond_init error");
          return (TH_FAIL);
     }
     return (TH_OK);
}
```

new: keep track of the # of active threads

new: init a mutex / thread

new: init a cond_var / thread

```
static void thread_signal_action(int signo)
{
     int i = 0, j;
     pthread_t this_one;
     {
          i = 1;
          this_one = pthread_self();

          for (j = 0; j <= MAX_THREAD; j++)
               if (thread_id[j] == this_one) {

                    while (i) {
                         if (pthread_mutex_lock(&sys_th_mut[j]) != 0) {
                              printf("thred_action 1: mutex_lock error\n");
                         }
#ifdef DEBUG
                         printf("waiting. . . .\n");
#endif
                         if (pthread_cond_wait(&sys_th_cond[j], &sys_th_mut[j]) == -1) {
                              printf("sys_th_action 2: cond_wait\n");
                              /* unlocks the mutex in case of error */
                              if (pthread_mutex_unlock(&sys_th_mut[j]) != 0) {
                                   printf("sys_th_action 3: mutex_unlock\n");
                              }
                         } else
                              i = 0;
#ifdef DEBUG
                         printf("phew... that was long!\n");
#endif
                    }
                    /* unlocks after the release */
                    if (pthread_mutex_unlock(&sys_th_mut[j]) != 0) {
                         printf("sys_th_action 4: mutex_unlock\n");
                    }
               }
     }
     return;
}
```

```
static void thread_signal_action(int signo)
{
     printf ("We got signal: %i\n",signo);
     if (signo == SUSPEND_SIGNAL) { sleep (1000000);}
     return;
}
```

changes

```
int waitfor_thread(long my_th_handler)
{
     int i, status;

     if (pthread_join((pthread_t)my_th_handler, (void **) &status) != 0) {
          printf("waitfor_thread: join error\n");
          return (TH_FAIL);
     }
     for (i = 0; i <= MAX_THREAD; i++)
          if (thread_id[i] == my_th_handler) {

               if (pthread_cond_destroy(&sys_th_cond[i]) != 0) {
                    printf("sys_waitfor_thread: cond_destroy error");
                    return (TH_FAIL);
               }
               if (pthread_mutex_destroy(&sys_th_mut[i]) != 0) {
                    printf("sys_waitfor_thread: mutex_destroy error");
                    return (TH_FAIL);
               }
     }
     return (TH_OK);

}
```

new: clean the cond_vars and mutexes

new: resume function

```
int resume_thread(long my_th_handler)
{
     int i, the_one = 0;
     for (i = 0; i <= MAX_THREAD; i++) {
          if (thread_id[i] == my_th_handler) the_one = i;
     }

     if (pthread_cond_broadcast(&sys_th_cond[the_one]) == -1) {
          printf("sys_resume_thread: cond_broadcast error");
          return (TH_FAIL);
     }
#ifdef DEBUG
     printf("the thread %d  is  back!!!!", the_one);
#endif

     return (TH_OK);
}
```

```
int exit_thread(long my_th_handler)
{
     if (my_th_handler == 0) {
          th_global_num--;
          pthread_exit(0);      /* If self, just exit */
     }
     if (pthread_cancel((pthread_t)my_th_handler) != 0) {
          printf("exit_thread: cancel error\n");
          return (TH_FAIL);
     }
#ifdef DEBUG
     printf("killed! %d \n", (my_th_handler));
#endif
     th_global_num--;
     return (TH_OK);
}
```

new: keep track of the # of active threads

```
     data = "GREEN";
     status = launch_thread(&th_handle1, test_thread, data);
     data = "orange";
     status = launch_thread(&th_handle2, test_thread, data);
     sleep(2);
     printf ("suspending TH2...\n");
     suspend_thread(th_handle2);
     sleep(2);
     printf ("resuming TH2...\n");
     resume_thread(th_handle2);
     sleep(1);
     printf("test DONE !\n");
     exit(0);
```

modify the testing part to suspend-resume

ex5.c

WITH C++11

```
#include <thread>
#include <chrono>
#include <iostream>
#include <csignal>
#include <mutex>
#include <condition_variable>

static int                signaled = 0;
std::mutex                mylock;
std::condition_variable th_cond;

void sighandler(int sig) {
  signaled = 1;
  std::cout << "signaled.\n";
}

void test_thread(std::string arg)
{
     std::signal(SIGINT, sighandler);
     int count=0;
     std::chrono::milliseconds duration( 400 );
     std::unique_lock<std::mutex> locker(mylock);
     th_cond.wait(locker);
     locker.unlock();
     while (count == 0 ) {
          std::cout << arg << std::endl;
          std::this_thread::sleep_for( duration );
          if (arg=="Orange" && signaled) count=1;
     }
}
//---------------------------------
int main(void)
{
     std::thread::id th_handle1, th_handle2, th_handle3;

     std::thread *t1 = new std::thread(test_thread, "Green");
     th_handle1=t1->get_id();

     std::thread *t2= new std::thread(test_thread, "Orange");
     th_handle2=t2->get_id();

     std::chrono::milliseconds duration( 4000 );
     std::this_thread::sleep_for( duration );

     std::cout << "notify..." <<std::endl;
     th_cond.notify_all();

     std::this_thread::sleep_for( duration );
     std::cout << "ask t2 to finish. suspending main." <<std::endl;
     std::raise (SIGINT);
     t2->join();
     delete(t2);
     std::cout << "t2 gone. t1 continues; main resumed." <<std::endl;

     std::this_thread::sleep_for( duration );
     std::cout << "test DONE !" <<std::endl;
     exit(0);
}
```

lock and wait

unlock when the wait is over

launch them all!

kill t2 after 4s

```
notify...
Orange
Green
OrangeGreen

OrangeGreen

GreenOrange

GreenOrange

Green
Orange
GreenOrange

Green
Orange
GreenOrange

OrangeGreen

ask t2 to finish. suspending main.
signaled.
Green
t2 gone. t1 continues; main resumed.
Green
Green
Green
Green
Green
Green
Green
Green
Green
Green
test DONE !
```

SUMMARY

- We need parallel (multi-threaded) programming to use the existing hardware with maximum efficiency.

- We have seen 3 different ways of parallel programming in unix
  - use pthreads with C
  - use pthreads with C++ *(not explicitly in the slides, but you can achieve this in a very simple way: just compile with g++)*
  - use std::thread in C++11

OUTLOOK

- limitations of multi threading / processing
  - amount of shared resources (& available memory) justifies launching multi threads.
  - Amdahl's Law: the speedup of a program due to parallelization can be no larger than the inverse of the portion of the program that is immutably sequential.
    - For example, if 50% of your program is not parallelizable, then you can only expect a maximum speedup of 2x
- processor affinity
  - a program or a thread can be locked to a particular CPU (or core). This will override the OS's scheduling scheme. The calls are OS dependent. *Linux*: taskset & sched_setaffinity for processes and pthread_setaffinity_np & pthread_attr_setaffinity_np, for *BSD check your manual.
- vector processing features in modern CPUs
  - vector processing: single operation on multiple data OR multiple operation on multiple data. example: scale a 1x100 vector by π . Knowing your hardware would allow writing more efficient software.

HOMEWORK

- Google the following higher level tools for parallel programming:
  - Boost, TBB, PROOF
- Make the last demo work on your computer w/ 3 colors.
  - make a real library with a .c and .h file + test suite + readme
  - challenge: could you make a resume_all_threads function?
- What are the futures and lambda functions in c++11?

- *References*
  - http://linux.about.com/library/cmd/blcmdl2_sched_setscheduler.htm
  - Programming with POSIX Threads: David R. Butenhof
  - https://computing.llnl.gov/tutorials/pthreads
  - http://www.cprogramming.com/c++11/c++11-lambda-closures.html