CONCURRENCY

PA193 - SECURE CODING PRINCIPLES AND PRACTICES

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QUICK QUIZ

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- What is concurrency?

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- Who provides threads?

QUICK QUIZ

- What is concurrency?
  - “ Concurrency is the decomposability property of a program, algorithm, or problem into order-independent or partially-ordered components or units.
- Thread x Process difference
  - Thread is minimal runnable unit for OS that can be deployed on processor, unlike process it does not own virtual memory, but uses virtual memory of parent process.
  - Every process has at least one thread, which is main for execution
- Who provides threads?
  - Threads are provided by OS, although many languages has their own implementation due to optimization.

THREADS

OPERATING SYSTEMS

UNIX:

- Pthread library part of POSIX
- #include <pthread.h>

WINDOWS:

- Defined in WIN32 API
- #include <windows.h>

MULTI PLATFORM:

- Since c11 and c++11 standards are threads part of standard library
- Qt framework
- Boost library

LANGUAGES

- **GO:** gorutines
- **ERLANG:** processes
- **ADA:** tasks

- **Java:** java.lang.Thread
- **Python:** thread and threading module

PTHREAD LIBRARY

- Part of POSIX library
- Provides basic interface for Thread management and mutual exclusion techniques
- All types and functions are prefixed with pthread string
- Needs to be compiled with **-pthread** argument, to link pthread library into binary
- All types and functions are descirbed in **pthread.h** header file

PTHREAD LIBRARY

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

- Creates new thread, which will start execution in **start_routine** function
- **thread** in/out attribute, after pthread_create is called, it's set to threads identifier
- **attr** thread attributes, typically passed NULL
- **start_routine** entry point of newly created thread
- **arg** arguments passed to start_routine
- **man 3 pthread_create**

```
int pthread_join(pthread_t thread, void **retval);
```

- Waits for thread to end execution and collect return value
- **thread** thread identifier, set by pthread_create
- **retval** if not set to NULL pthread_join will store start_routine return value in it.
- **man 3 pthread_join**

CRITICAL SECTION

- Point of code where shared resource is manipulated.
- Must be executed exclusively - only one thread at time
- **Even read operations must be exclusive**
  - Context switch can happen in the middle of read operation
  - Then data can be inconsistent
- Goal is to make critical section as small as possible
- Use mutual exclusion to achieve exclusivity

MUTUAL EXCLUSIONS

- Posix defines several methods of mutual exclusion
- Mutex - **Mut**ual **Ex**clusion
- Condition variable
- Semaphore

MUTEX

- Object which can be in two states, locked and unlocked
- When thread wants to enter critical section, it locks mutex
- When other thread tries to lock mutex, the execution will be stopped and will wait until mutex is unlocked by blocking thread
- When thread is leaving critical section, it unlocks the mutex
- **man 3 pthread_mutex_lock**

```
#include <pthread.h>
int pthread_mutex_destroy(pthread_mutex_t *mutex);
int pthread_mutex_init(pthread_mutex_t *restrict mutex,
           const pthread_mutexattr_t *restrict attr);
pthread_mutex_t mutex = PTHREAD_MUTEX_INITIALIZER;
int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_trylock(pthread_mutex_t *mutex);
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

CONDITION VARIABLE

- Critical section can be entered after condition is met
- Typically in producer-consumer applications, where consumer needs to wait for producer
- Consumer locks mutex, but finds, that it cannot enter critical section
- It calls **pthread_cond_wait** and sleeps, mutex is unlocked
- When producer creates new resource, it calls **pthread_cond_signal**
- All threads waiting for condition are waked and tries to obtain lock, check condition and if its met, they enter critical section with locked mutex
- **man 3 pthread_cond_init**

```
#include <pthread.h>
int pthread_cond_destroy(pthread_cond_t *cond);
int pthread_cond_init(pthread_cond_t *restrict cond,
           const pthread_condattr_t *restrict attr);
pthread_cond_t cond = PTHREAD_COND_INITIALIZER;
int pthread_cond_signal(pthread_cond_t *cond);
int pthread_cond_wait(pthread_cond_t *restrict cond,
           pthread_mutex_t *restrict mutex);
```

SEMAPHORES

- Integer value that identifies how many resources are consumable
- Every time the new resource is created, or released the counter is increased
- Every time resource is consumed the counter is decreased.
- Thread that tries to use resource sleeps until resource is allocated
- This allows multiple threads enter critical section when there are enough resources
- Sometimes it needs to be used with mutex, due to possible inconsistencies.
- **man 3 sem_init**

```c
#include <semaphore.h>

int sem_init(sem_t *sem, int pshared, unsigned int value);
int sem_destroy(sem_t *sem);
int sem_post(sem_t *sem);
int sem_wait(sem_t *sem);
```

HELGRIND

- Part of valgrind tool for dynamic analysis
- Designed to find bugs in threaded code
- Executed similarly to memcheck
- **valgrind --tool=helgrind ./your_code**
- Your code should be compiled with debugging symbols **"gcc -g ...."**
- http://valgrind.org/docs/manual/hg-manual.html

TASKS

Work on **labak.fi.muni.cz** via putty or on your computer if you have linux

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2. Increase number of threads to 100 and wait for problems to appear
3. Try to find problems with helgrind

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4. Add locking to your program

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5. Try helgrind to find possible race conditions

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6. Modify your code to create deadlock

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6. Modify your code to create deadlock
7. Test it with helgrind

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6. Modify your code to create deadlock
7. Test it with helgrind
8. Fix your code, so deadlock won't happen.

ASSIGNMENT

- Simple thread pool
- You are provided with simple queue and worker interface
- **Deadline: 2018-11-15 24:00 CET (23:00 UTC)**

Goals:

- Make the queue thread safe - enqueue and dequeue can happen from different threads
- Modify worker, so that it will in worker_init spawn several threads, which will wait for jobs to appear in queue
- You can add any attribute to structures to achieve thread safety
- You should write your own tests for queue and worker to prove their safety
- Test all with helgrind, and save the outputs
- Write tests, that will execute your worker and queue in specified situations - pop of empty queue, push to empty queue etc. (Without tests up to 2 points might be deducted)

Report:

- As a part of assignment you will submit report
- There you'll describe how did you achieve thread safety
- What bugs you have found during development with helgrind
- If you can't of won't make any bugs during development, then try to make some in tests and describe them in report as well.
- You should report at least 5 different errors found by helgrind, how those bugs were made, and how you fixed them

CONCLUSION

- **Don't be afraid of threads**
- **Use threads in your applications**
- You should keep in mind dangers that concurrency can create in your code
- Always try to make critical sections as minimal as possible
- Use mutexes, semaphores and other tools to avoid race conditions, deadlocks and other possible issues
- Check your code with helgrind, it can save you many hours of debugging
- Write your code with concurrency in mind, you might not want to write concurrent library, but someone will eventually try to use it with threads
- Many frameworks and libraries uses threads, even though you don't know it
- Last but not least: **Test your code!**
  - **Multi threaded applications are hard to debug, you need to be sure, that particular function/method is doing what it should do!**

QUESTIONS?

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THANK YOU!