Introduction to Lab 3

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What is lab 3?

... who cares about scalability anyway?

The purpose of this assignment is to give insights into:

1. how to program multi-processors
2. introduce the pthreads threading API
3. how different sharing patterns can affect performance
4. show how algorithm design affects scalability

What is Gauss-Seidel?

... and why do I care?

Gauss-Seidel is:

- an iterative linear equation solver.
- ancient and low-performing on its own.
- used as a component in modern multi-grid solvers.

How we will use Gauss-Seidel

We will use Gauss-Seidel to solve the Laplace equation:

$$\begin{aligned} \Delta u = \frac{\delta^2 u}{\delta x^2} + \frac{\delta^2 u}{\delta y^2} &= 0 \quad \texttt{in}\ \Omega \\ u &= 0 \quad \texttt{on}\ \delta\Omega \end{aligned}$$

Note: The equation above is not a linear equation system!

... but we can approximate it as one using finite differences!

$$\Delta u_{i,j} \approx \frac{u_{i-1,j} + u_{i+1,j} + u_{i,j-1} + u_{i,j+1} - 4u_{i,j}}{h^2}$$

The Gauss-Seidel algorithm
A sweep

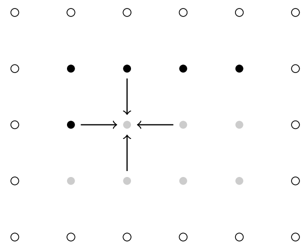
Generally:

$$x_i^{k+1} = \frac{b_i - \sum_{j<i} a_{ij} x_j^{k+1} - \sum_{j>i} a_{ij} x_j^k}{a_{ij}}$$

Applied to the Laplace equation (with $h = 1$):

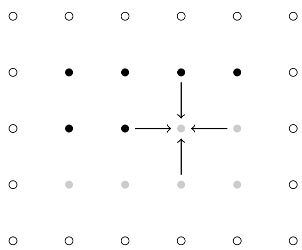
$$u_{i,j}^{k+1} = \frac{u_{i-1,j}^{k+1} + u_{i,j-1}^{k+1} + u_{i+1,j}^k + u_{i,j+1}^k}{4}$$

Access pattern
Serial version



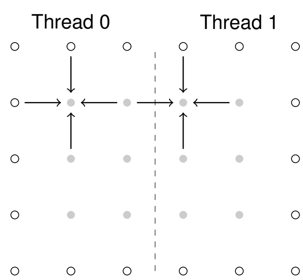
Each element is the average of its neighbors. The “new” value is used for the north and west neighbor.

Access pattern
Serial version



Each element is the average of its neighbors. The “new” value is used for the north and west neighbor.

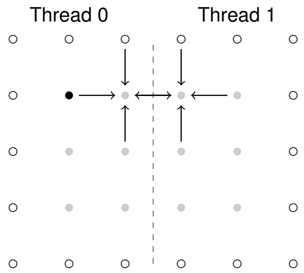
Access pattern
Parallel version



We will parallelize column wise. This requires synchronization between the threads along the “border”. You will implement that synchronization.

Access pattern

Parallel version



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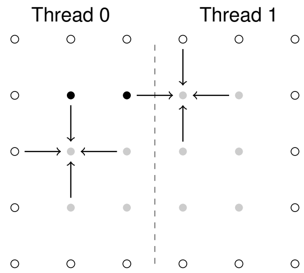

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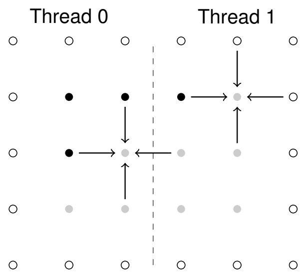

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The Gauss-Seidel algorithm

Testing for convergence

We define convergence as:

$$\sum_i \sum_j |u_{i,j}^k - u_{i,j}^{k+1}| \leq t$$

We say that the algorithm has converged when the absolute difference between two iterations is smaller than the tolerance.

What are *Posix Threads*?

Pthreads is:

- a standardized way to create and synchronize threads
- the default threading API on most Unix systems. This includes:
  - GNU/Linux
  - (Net|Free|...)BSD
  - Sun Solaris
  - Apple MacOS X
  - ...

Creating threads

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

Parameters:

thread Where to store the thread ID.

attr Attributes for the thread, NULL defaults.

start_routine Procedure to call in the new thread.

arg Argument passed to `start_routine`

Return Value:
0 if successful, error number otherwise.

Waiting for threads to terminate

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

Parameters:

thread Thread to wait for.

value_ptr Pointer to variable to store return value in, NULL to discard return value.

Return Value:
0 if successful, error number otherwise.

Thread creation

An example

```
#include <pthread.h>
#include <stdio.h>

static void *my_thread(void *arg) {
        printf("Hello␣Threads!\n");
        return NULL;
}

int main(int argc, char *argv[]) {
        pthread_t thread;
        /* TODO: No error handling :( */
        pthread_create(&thread, NULL,
                       my_thread, NULL);
        pthread_join(thread, NULL);
        return 0;
}
```

Mutexes
Initialization

```
int pthread_mutex_init(
        pthread_mutex_t *mutex,
        const pthread_mutexattr_t *attr);
```

Parameters:

mutex Pointer to mutex to initialize.

attr Pointer to mutex attributes, NULL for default attributes.

Return Value:
0 if successful, error number otherwise.

Mutexes
Initialization

```
pthread_mutex_t mutex =
        PTHREAD_MUTEX_INITIALIZER;
```

Mutex initialization the easy way, uses default attributes. No need for explicit cleanup.

Mutexes
Cleanup

```
int pthread_mutex_destroy(
        pthread_mutex_t *mutex);
```

Parameters:

mutex Pointer to mutex to destroy.

Return Value:
0 if successful, error number otherwise.

Mutexes
Locking

```
int pthread_mutex_lock(
        pthread_mutex_t *mutex);
int pthread_mutex_unlock(
        pthread_mutex_t *mutex);
```

Parameters:

mutex Pointer to mutex to lock or unlock.

Return Value:
0 if successful, error number otherwise.

Mutexes
Example

```
static int balance = 512;
static pthread_mutex_t balance_mutex =
         PTHREAD_MUTEX_INITIALIZER;

static int withdraw(int amount) {
         int ret = 0;
         pthread_mutex_lock(&balance_mutex);
         if (balance > amount) {
                  balance -= amount;
                  ret = amount;
         }
         pthread_mutex_unlock(&balance_mutex);
         return ret;

}
```

Barriers
Initialization

```
int pthread_barrier_init(
         pthread_barrier_t *barrier,
         const pthread_barrierattr_t *attr,
         unsigned count);
```

Note:
Barriers are *optional* in the Posix specification.

Parameters:

- barrier Pointer to barrier to initialize.
- attr Pointer to barrier attributes, NULL for defaults.
- count Number of threads to wait for.

Return Value:
0 if successful, error number otherwise.

Barriers
Cleanup

```
int pthread_barrier_destroy(
         pthread_barrier_t *barrier);
```

Parameters:

- barrier Pointer to barrier to destroy.

Return Value:
0 if successful, error number otherwise.

Barriers
Waiting

```
int pthread_barrier_wait(
         pthread_barrier_t *barrier);
```

Parameters:

- barrier Pointer to barrier to wait for.

Return Value:
`PTHREAD_BARRIER_SERIAL_THREAD` or 0 on success, error number otherwise.

Barriers
Example

```
static pthread_barrier_t barrier;

static void init_barrier() {
        pthread_barrier_init(&barrier, NULL,
                             2);
}
static void destroy_barrier() {
        pthread_barrier_destroy(&barrier);
}
static void do_stuff() {
        /* TODO: Super-fancy algorithm here */
        pthread_barrier_wait(&barrier);

}
```

Documentation
... or the answer to *Life, the Universe and Everything*

There are two sources of "truth" if you are hacking Unix:

- The Single Unix Specification[1]
- Your local system's man-pages, for example:
  ```
  host$ man man
  host$ man pthreads
  ```

[1] http://www.unix.org/single_unix_specification/

Files in the lab package

Makefile	Controls compilation. Contains a *test* target.
gs_common.c	Boring stuff you don't need to touch.
gs_interface.h	Contains declarations and documentation for the interface between `gs_common.c` and your GS implementation.
gsi_seq.c	Sequential reference implementation.
gsi_pth.c	Write *your* code here.

Demonstration

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Important dates

- Groups:

  Prep. Room 1412D, 13:15–17:00
  A 2012-11-13, Room 1412D, 13:15–17:00
  B 2012-11-15, Room 1412D, 08:15–12:00
  C 2012-11-16, Room 1412D, 08:15–12:00
- Deadline: Lab occasions

Summary

- You will:
  - Parallelize a Gauss Seidel implementation using Pthreads and flag synchronization
  - Study the performance of your parallel implementation
  - Perform architecture specific optimizations on the parallel application
- Complete lab manual on the course homepage[2]

[2] `http://www.it.uu.se/edu/course/homepage/avdark/ht12`

Summary

And remember…

Thou shalt study thy libraries and strive not to reinvent them without cause, that thy code may be short and readable and thy days pleasant and productive.[3]

[3] `http://www.lysator.liu.se/c/ten-commandments.html`