CS528
Multi-threading

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Threading Language and Support

- Pthread: POSIX thread
  - Popular, Initial and Basic one
- Improved Constructs for threading
  - c++ thread : available in c++11, c++14
  - Java thread : very good memory model
    - Atomic function, Mutex
- Thread Pooling and higher level management
  - OpenMP (loop based)
  - Cilk (dynamic DAG based)

Pthread, C++ Thread, Cilk and OpenMP

```
pthread_t tid1, tid2;
pthread_create(&tid1, NULL, Fun1, NULL);
pthread_create(&tid2, NULL, Fun2, NULL);
pthread_join(tid1, NULL);
pthread_join(tid2, NULL);
```

Pthread

```
thread t1(Fun1);
thread t1(Fun2, 0, 1, 2); // 0, 1,2 param to Fun2
t1.join();
t2.join();
```

C++ thread

```
#pragma omp parallel for
for(i=0;i<N;i++)
     A[i]=B[i]*C[i];
//Auto convert serial code to threaded code
// $gcc -fopenmp test.c; export OMP_NUM_THREADS=10; ./a.out
```

```
cilk fib (int n){//Cilk dynamic parallism, DAG recursive code
      if (n<2) return n;
      int x=spawn fib(n-1); //spawn new thread
      tnt y=spawn fib(n-2); //spawn new thread
      sync;
      return x+y;
}
```

Programming with Threads

- Threads
- Shared variables
- The need for synchronization
- Synchronizing with semaphores
- Thread safety and reentrancy
- Races and deadlocks

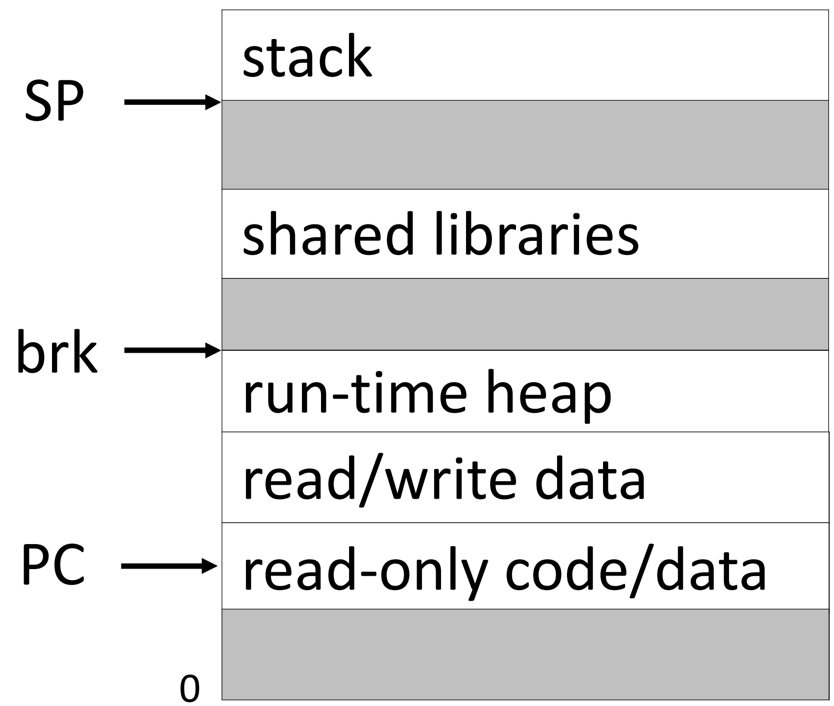
Traditional View of a Process

- Process = process context + code, data, and stack

Process context

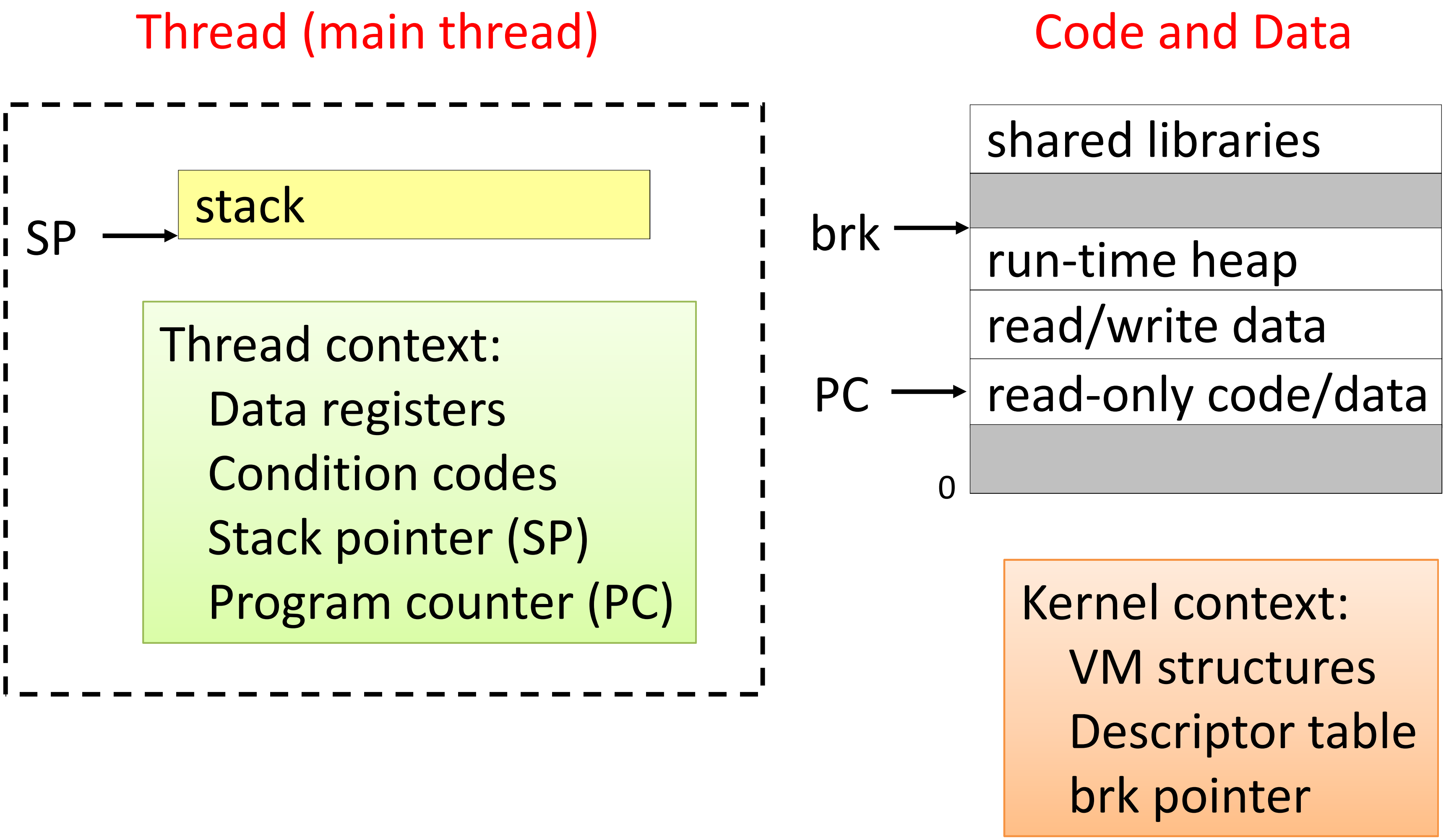
Program context:
  Data registers
  Condition codes
  Stack pointer (SP)
  Program counter (PC)
Kernel context:
  VM structures (VMem)
  Descriptor table
  brk pointer

Code, data, and stack



Alternate View of a Process

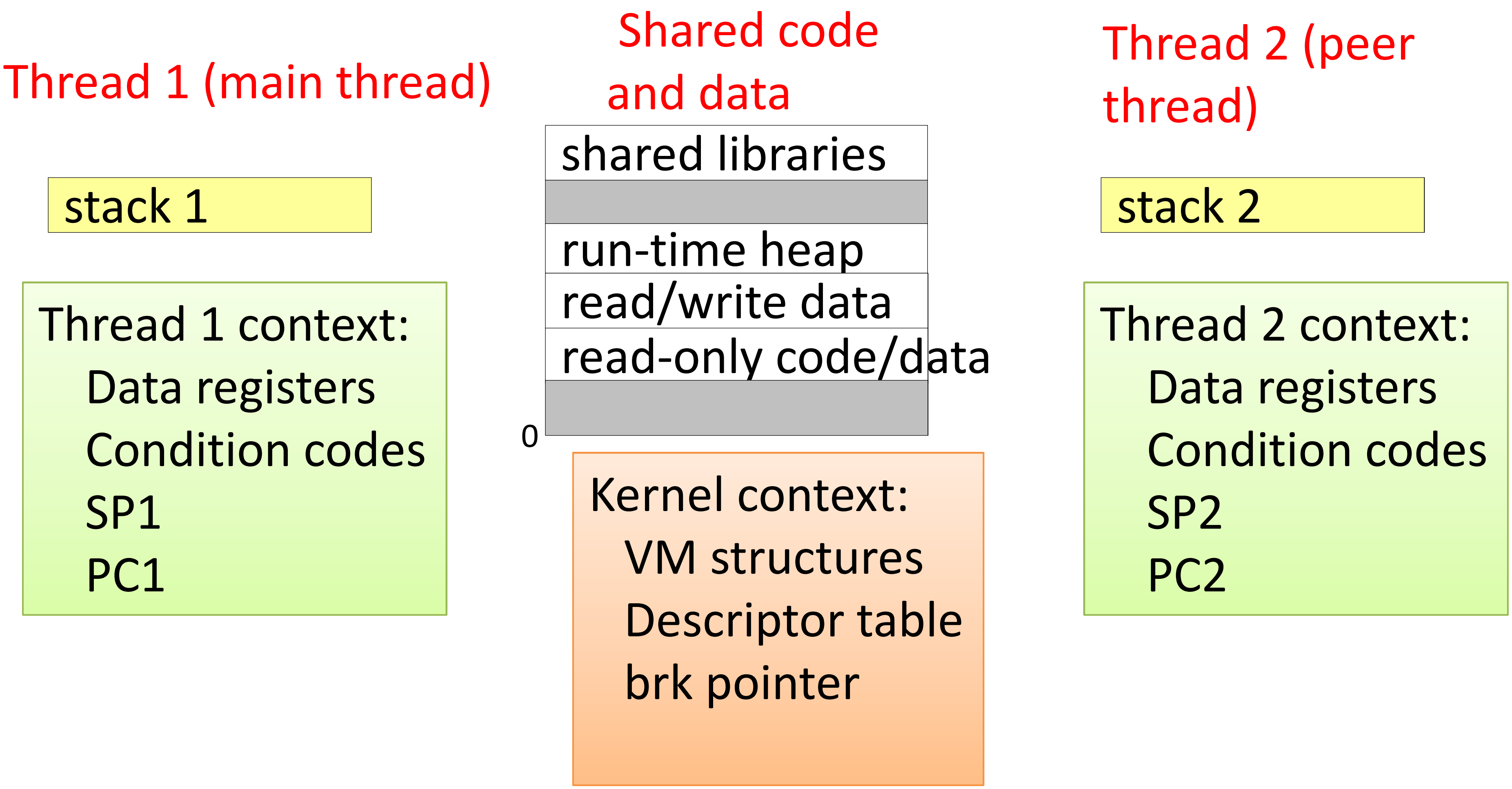
- Process = thread+ code, data & kernel context



A Process With Multiple Threads

- Multiple threads can be associated with a process
  - Each thread has its *own* logical control flow (sequence of PC values)
  - Each thread *shares* the same code, data, and kernel context
  - Each thread has its own thread id (TID)

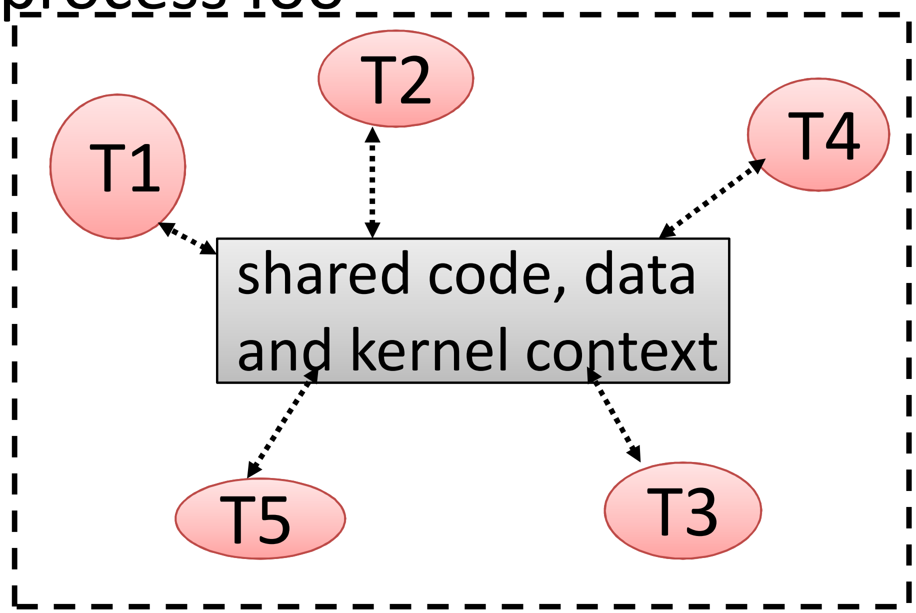
A Process With Multiple Threads



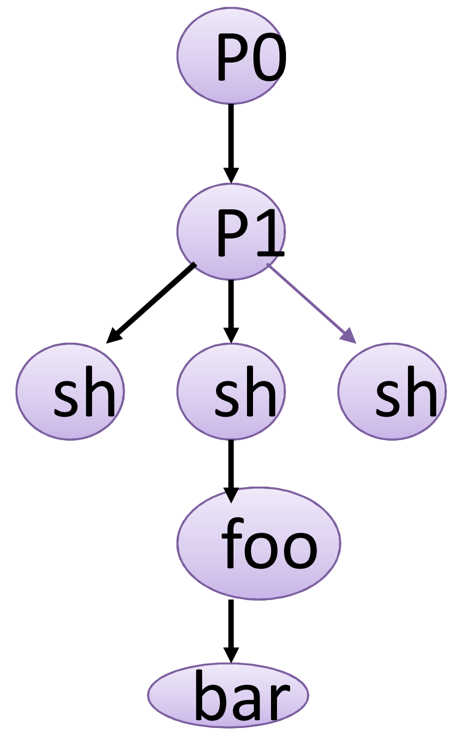
Logical View of Threads

- Threads associated with a process form a pool of peers
  - Unlike processes, which form a tree hierarchy

Threads associated with process foo



Process hierarchy



Threads vs. Processes

- How threads and processes are similar
  - Each has its own logical control flow
  - Each can run concurrently
  - Each is context switched

Threads vs. Processes

- How threads and processes are different
  - Threads share code and data, processes (typically) do not
  - Threads are somewhat less expensive than processes
    - Process control (creating and reaping) is twice as expensive as thread control
    - Linux/Pentium III numbers:
      - ~20K cycles to create and reap a process
      - ~10K cycles to create and reap a thread

Posix Threads (Pthreads) Interface

- **Creating and reaping threads**
  - `pthread_create, pthread_join`
- **Determining your thread ID :** `pthread_self`
- **Terminating threads**
  - `pthread_cancel, pthread_exit`
  - `exit` [terminates all threads] , `return` [terminates current thread]
- **Synchronizing access to shared variables**
  - `pthread_mutex_init, pthread_mutex_[un]lock`
  - `pthread_cond_init, pthread_cond_[timed]wait`

The Pthreads "hello, world" Program

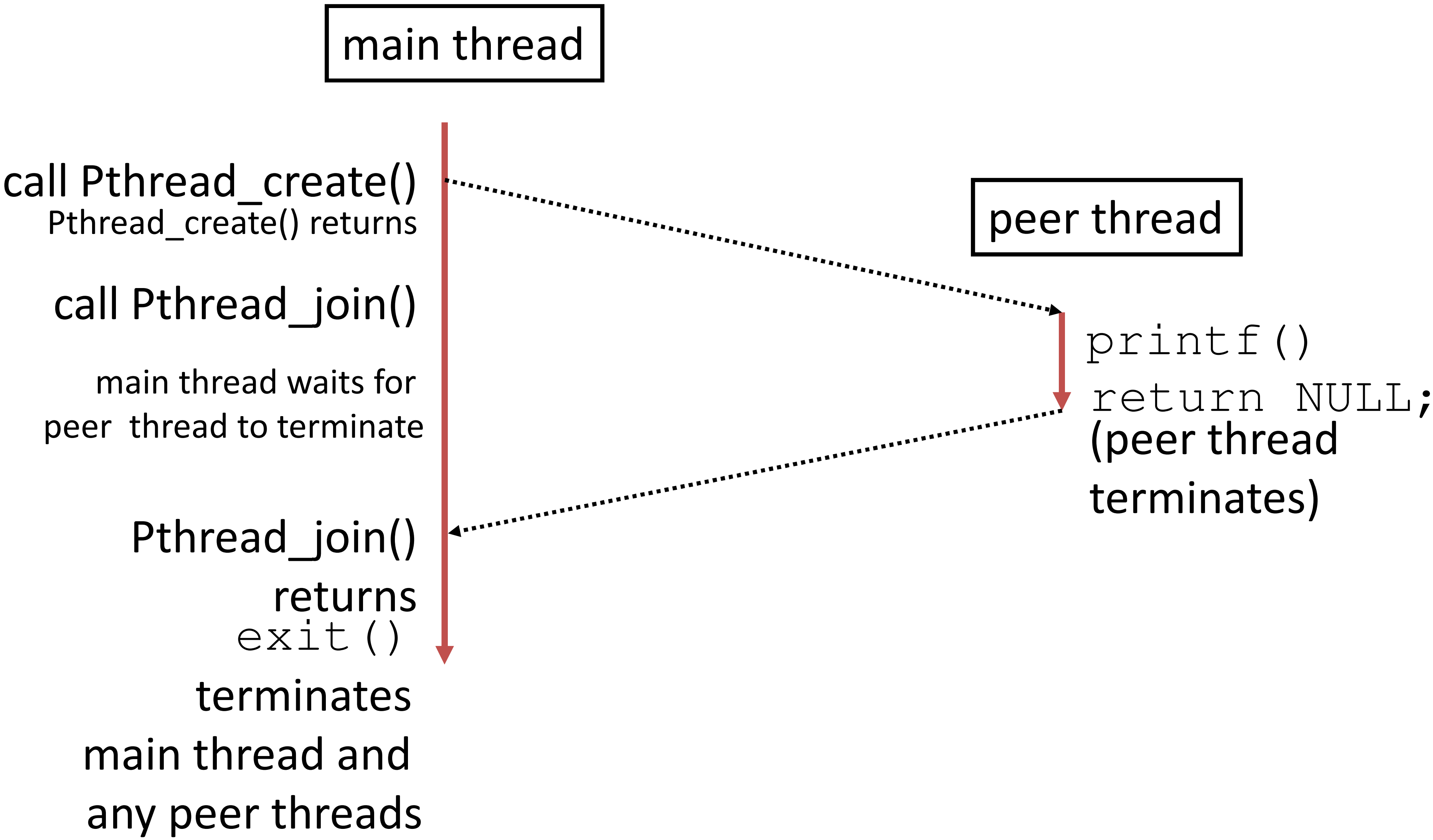
```
/* thread routine */
void *HelloW(void *vargp) {
  printf("Hello, world!\n");
  return NULL;
}

int main() {
  pthread_t tid;
  pthread_create(&tid, NULL, Hellow, NULL);
  pthread_join(tid, NULL);
  return 0;
}
```

Thread attributes (usually NULL)

*Thread arguments (void *p)*

*return value (void **p)*

Execution of Threaded "hello, world"



Pros and Cons: Thread-Based Designs

- **+ Easy to share data structures between threads**
  - E.g., logging information, file cache
- **+ Threads are more efficient than processes**
- **– Unintentional sharing can introduce subtle and hard-to-reproduce errors!**
  - Ease of data sharing is greatest strength of threads
  - Also greatest weakness!

VectorSum Serial

```
int A[VSize], B[VSize], C[VSize];


void VectorSumSerial(){
   for( int j=0;j<SIZE;j++)
     A[j]=B[j]+C[j];
}
```

Suppose Size=1000

0-249	250-499	500-749	750-999
T1	T2	T3	T4

VectorSum Serial

```
int A[VSize], B[VSize], C[VSize];


void VectorSumSerial(){
   for( int j=0;j<SIZE;j++)
     A[j]=B[j]+C[j];
}
```

- Independent
- Divide work into equal for each thread
- Work per thread: Size/numThread

VectorSum Parallel

```
void *DoVectorSum(void *tid){
    int j, SzPerthrd, LB, UB, TID;
     TID= *((int *)tid);
     SzPerthrd=(VSize/NUM_THREADS);
     LB= SzPerthrd*TID;UB=LB+SzPerthrd;


    for(j=LB;j<UB;j++)
      A[j]=B[j]+C[j];
}
```

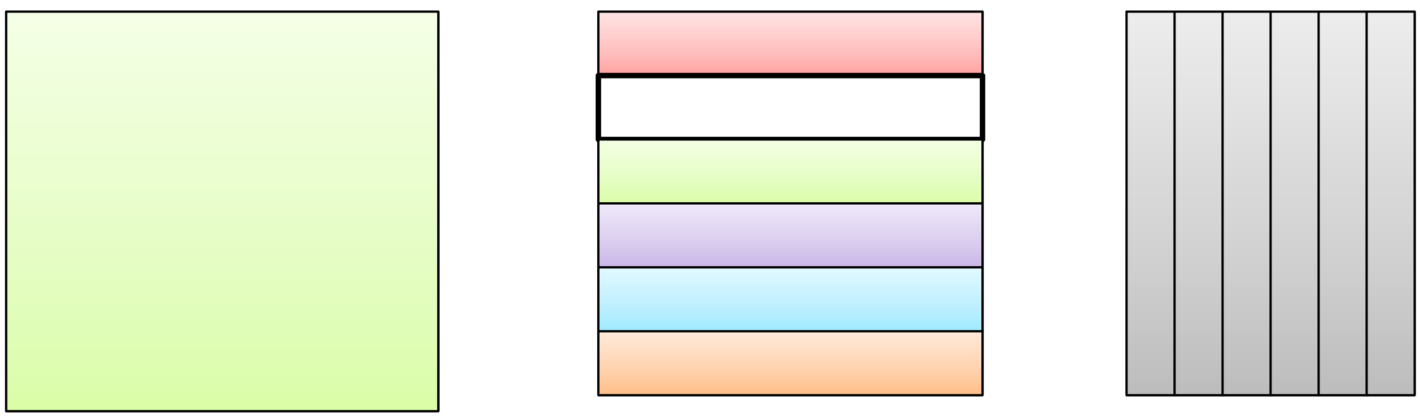
VectorSum Parallel

```
int main(){
    int i;
    pthread_t thread[NUM_THREADS];
    for (i = 0; i < NUM_THREADS; i++)
        pthread_create(&thread[i],
        NULL, DoVectorSum, (void*)&i);
    for (i = 0; i < NUM_THREADS; i++)
        pthread_join(thread[i], NULL);

    return 0;
}
```

Matrix multiply and threaded matrix multiply

- Matrix multiply: C = A × B

$$C[i,j] = \sum_{k=1}^{N} A[i,k] \times B[k,j]$$



Matrix multiply and threaded matrix multiply

- Matrix multiply: C = A × B

$$C[i,j] = \sum_{k=1}^{N} A[i,k] \times B[k,j]$$

- Divide the whole rows to T chunks
  - Each chunk contains : N/T rows, Assume N%T=0

Matrix multiply Serial

```
void MatMul(){
    int i,j,k,S;
    for(i=0;i<Size;i++)
     for(j=0;j<Size;j++){
        S=0;
        for(k=0;k<Size;k++)
            S=S+A[i][k]*B[k][j];
        C[i][j]=S;
     }
  }
```

Matrix Pthreaded: RowWise

```
void * DoMatMulThread(void *arg){
     int i,j,k,S,LB,UB, TID, ThrdSz;
     TID=*((int *)arg);ThrdSz=Size/NumThrd;
     LB=TID*ThrdSz;UB=LB+ThrdSz;
     for(i=LB;i<UB;i++)
          for(j=0;j<Size;j++){
          S=0;
          for(k=0;k<Size;k++)
            S=S+A[i][k]*B[k][j];
          C[i][j]=S;
          }
 }
```

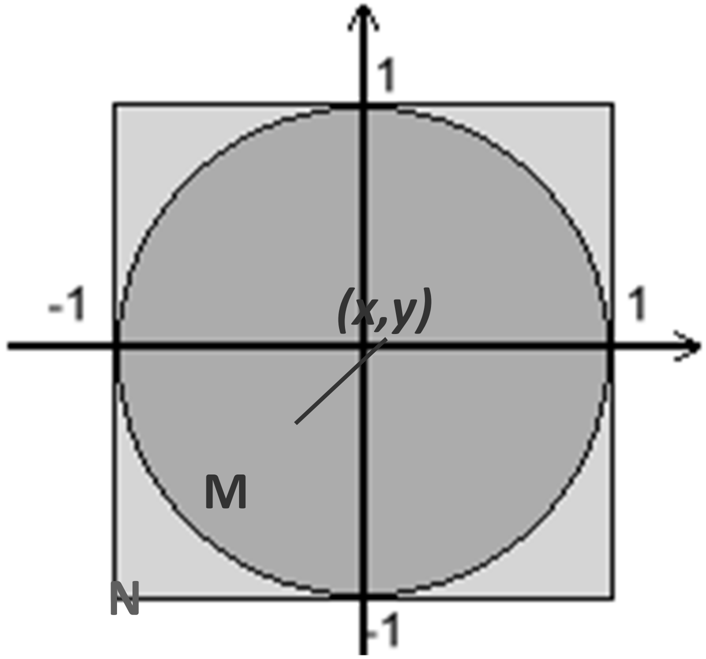
Matrix Pthreaded: RowWise

```
int main(){
    pthread_t thread[NumThread];
    int t;
    Initialize();
     for(t=0; t<NumThread; t++)
           pthread_create(&thread[t], NULL,
           DoMatMulThread, &t);
     for(t=0; t<NumThread; t++)
           pthread_join(thread[t], NULL);
     TestResult();
     return 0;
}
```

Estimating π using Monte Carlo

- The probability of a random point lying inside the unit circle:

$$\mathbf{P}\left(x^2+y^2<1\right)=\frac{A_{circle}}{A_{square}}=\frac{\pi}{4}$$



- If pick a random point *N* times and *M* of those times the point lies inside the unit circle:

$$\mathbf{P}^{\circ}\left(x^2+y^2<1\right)=\frac{M}{N}$$

- If *N* becomes very large, P=P^0

$$\pi=\frac{4\cdot M}{N}$$

Value of PI: Monte-Carlo Method

```
void MontePI(){
   int count=0,i;
    double x,y,z;
    for ( i=0; i<niter; i++) {
        x = (double)rand()/RAND_MAX;
        y = (double)rand()/RAND_MAX;
        z = x*x+y*y;
        if (z<=1) count++;
        }
    pi=(double)count/niter*4;
}
```

PI- Multi-threaded

- 1 thread you are able to generate N points
  - Suppose M points fall under unit circle
  - PI=4M/N
- With 10 thread generate 10XN points and calculate more accurately
  - Each thread calculate own value of PI (or M)
  - Average later on (or recalculate PI from collective M)

Value of PI: Pthreaded

```
int main(){
   pthread_t thread[NumThread]; double pi;
   int t, at[NumThread], count, TotalIter;
    for(t=0; t<NumThread; t++)
      pthread_create(&thread[t], NULL,
          DoLocalMC_PI, &t);
    for(t=0; t<NumThread; t++)
      pthread_join(thread[t], NULL);
    for(t=0;t<NumThread;t++) count+=LCount[t];
    TotalIter=niter*NumThread;
    pi=((double)count/TotalIter)*4;
    return 0;
}
```

Value of PI: Pthreaded

```
int LCount[NumThread];
void *DoLocalMC_PI(void *aTid){
   int tid, count, i; double x,y,z;
    tid= *((int *)aTid);
    count=0;LCount[tid]=0;
    for ( i=0; i<niter; i++) {
        x = (double)rand()/RAND_MAX;
        y = (double)rand()/RAND_MAX;
        z = x*x+y*y; if (z<=1) count++;
        }
    LCount[tid]=count;
}
```

What is the sieve of Eratosthenes?

- Used to find prime number between 2 and N
- It works by gradually eliminating multiple of smallest unmark prime (x) in the given interval
  - Till $x^2 > N$

Sieve of Eratosthenes

- Current Prime 2

[2,3,4,5,6,7,8,9,10,11,12,13, 14,15,16,17,18,19,20]

- Current Prime 2

[2,3,~~4~~,5, ~~6~~,7,~~8~~,9,~~10~~,11,~~12~~,13,~~14~~,15,~~16~~,17,~~18~~,19,~~20~~]

- Current Prime 3

List : [2, 3, 5, 7, 9, 11, 13, 15, 17, 19]

- Current Prime 3

List : [2, 3, 5, 7, ~~9~~, 11,13,~~15~~, 17,19]

- Current Prime 5 and 5 = ceil(sqrt(20))

List : [2, 3, 5, 7, 11, 13, 17,19] //All are primes

Sieve of Eratosthenes

```
int prime[MaxNum], CurrPrime;
void DoStriking(){
 for(int i=2*CurrPrime;i<MaxNum;
        i=i+CurrPrime)   prime[i]=0;
}
int main() {
   int i, sqrtmaxnum=sqrt(MaxNum)+1;
   for(i=0;i<MaxNum;i++)  prime[i]=1;
   for(i=2;i<sqrtmaxnum;i++){
        if (prime[i]==0) continue ;
        CurrentPrime=i; DoStriking();
   }
}
```

Sieve of Eratosthenes: Pthreaded

```
void *DoStriking(void *tid){
    int i, SizePerThrd, LB, UB;
    int TID= *((int *)tid);
    SizePerThrd =(MaxNum/NUM_THREADS);
    LB= SizePerThrd * TID;
    UB=LB + SizePerThrd;
    if(LB<(2*CurrPrime))LB=2*CurrPrime;
    for(i=LB;i<UB;i=i+CurrPrime)
         prime[i]=0;
}
```

Sieve of Eratosthenes: Pthreaded

```
for(i=2;i<sqrtmaxnum;i++){
    if (prime[i]==0) continue ;
    CurrPrime=i;
    for (j = 0; j < NUM_THREADS; j++)
        pthread_create(&thread[j],
          NULL, DoStriking, (void*)&j);
    for (j = 0; j < NUM_THREADS; j++)
        pthread_join(thread[j],NULL);
  }
```

Shared Variables in Threaded C Programs

- Question: Which variables in a threaded C program are shared variables?
  - Answer not as simple as “global variables are shared” and “stack variables are private”
- Requires answers to the following questions:
  - What is the memory model for threads?
  - How are variables mapped to memory instances?
  - How many threads reference each of these instances?