CS4414 Recitation 7

Prelim Review

10/08/2021

Alicia Yang

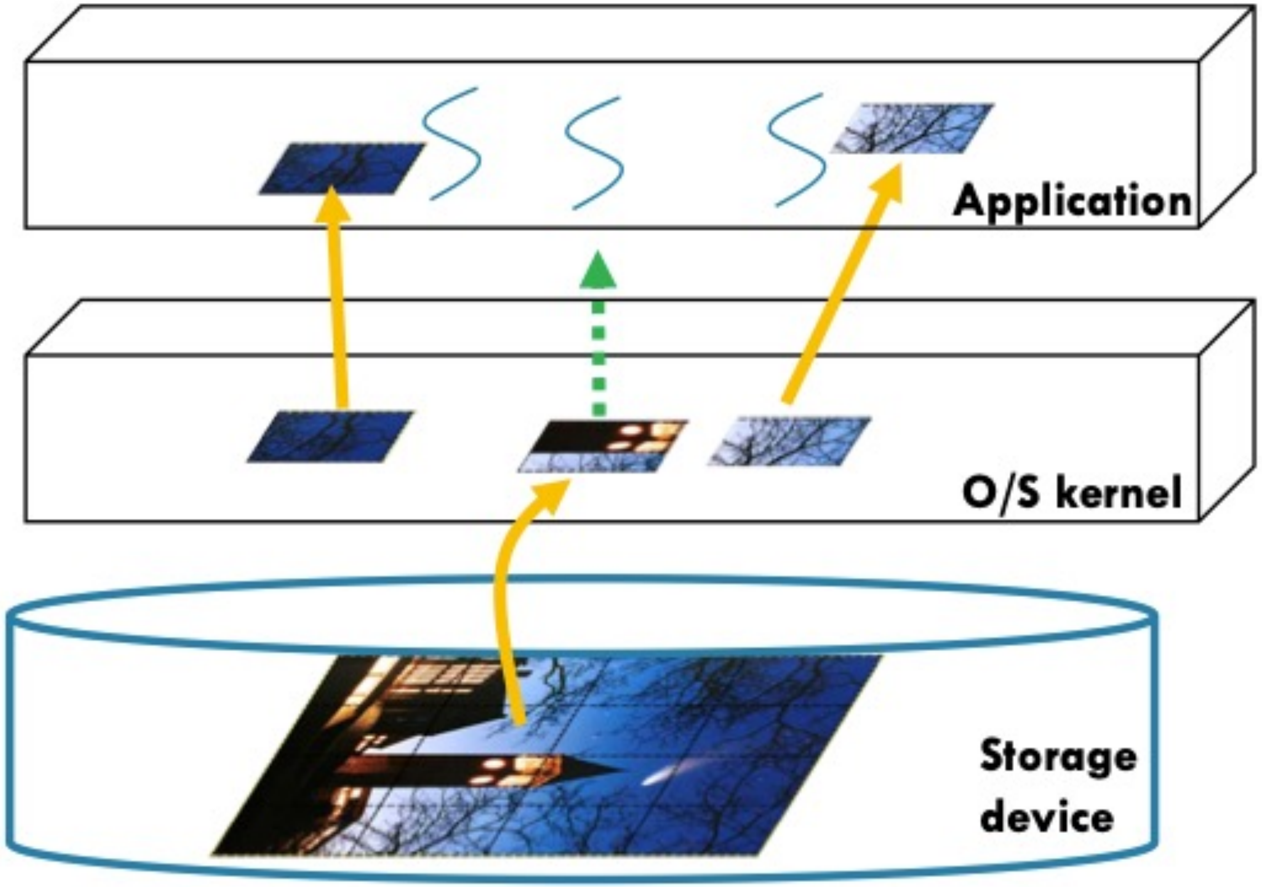
Reference lecture slides:
https://www.cs.cornell.edu/courses/cs4414/2021fa/Schedule.htm

Controlling Element in System

- Hardware Parallelism
- Constant Expression
- Templates
- Performance
- Linking

Hardware Parallelism

- There are opportunities to several parallel processing at every level



The application has multiple threads and they are processing different blocks. The blocks themselves are arrays of pixels

Block in the buffer pool was just read by the application. Next block is being prefetched… previously read blocks are cached, for a while

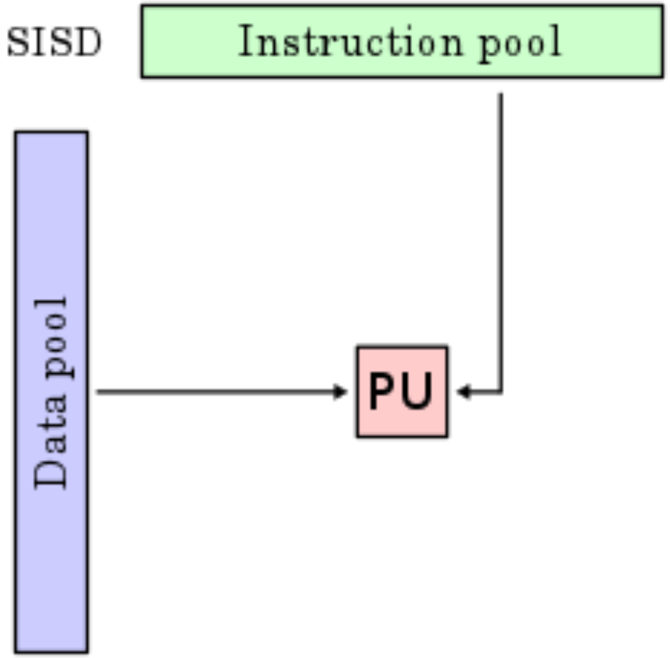
Photo on disk: It spans many blocks of the file. Can they be prefetched while we are processing blocks already in memory?

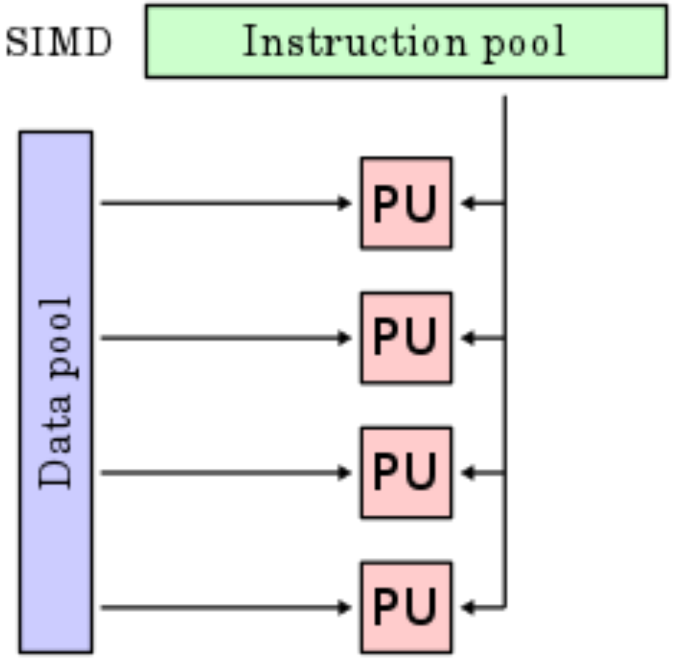
Reference lecture slides:
https://www.cs.cornell.edu/courses/cs4414/2021fa/Schedule.htm

Hardware Parallelism

- SISD and SIMD
  - SISD(**Single** instruction stream, **single** data stream)
  - SIMD(**Single** instruction stream, **multiple** data stream): One instruction perform the work on multiple data at the same time

    3D graphics, image processing, signal processing, video encoding

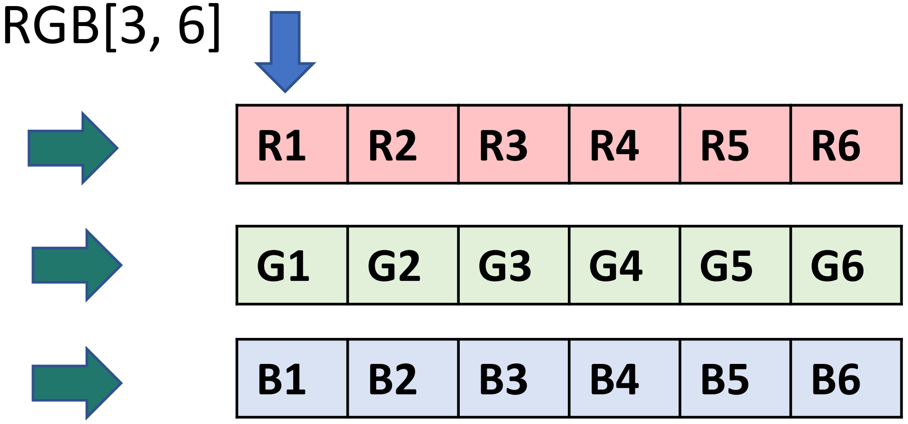




Hardware Parallelism

- SISD and SIMD
  - SISD(**Single** instruction stream, **single** data stream): The sequential processor takes data from a single address in memory and performs a single instruction on the data.
  - SIMD(**Single** instruction stream, **multiple** data stream): One instruction perform the work on multiple data streams at the same time

RGB[3, 6]



Compute 1/3(R + G + B) ?

Hardware Parallelism

- SIMD vs SISD
- How to program C++ to create parallel instruction? (vectorization)
  - C++ will search for vectorization opportunities if asked for, via **-ftree-vectorize** or **–O3** flags to the C++ command line.

Hardware Parallelism

- SIMD vs SISD
- How to program C++ to create parallel instruction? (vectorization)
  - GNU C++ programming to make parallelize automatically (requires "feature" that indicates the vectorization capabilities)

Loop

```
int a[256], b[256], c[256];
foo () {
   int i;
   for (i=0; i<256; i++){
      a[i] = b[i] + c[i];
}
}
```

Read accesses

```
int a[256], b[256];
foo (int x) {
   int i;
   for (i=0; i<N; i++){
     a[i] = b[i+x];
   }
}
```

....

https://gcc.gnu.org/projects/tree-ssa/vectorization.html

Const expression

Const expression

- Const is a promise that specifies that the object or variable is not modifiable.
- Const keywords can be attached with:
  - Variable
  - Pointer variable
  - Function: member function & return or parameter
  - Const expression

Const expression -- variable and pointer

- **Variable:** Syntactically specify the variable is not going to be changed

```
const int MAX_VAL = 100;
```

- **Pointer:** (const before and after the * are different)
  1. const type* var_name: Not allow changing the content of the variable pointer is pointing to, but could change the pointer address

     ```
     const  int* a = new int;            //   or int const* a = new int;   (same effect)
     *a = 2;
     a = (int*) & MAX_VAL;
     ```

  2. type* const var_name: Not allow to change the address, but could change the content

     ```
     int* const a = new int;
     *a = 2;
     a = (int*)&MAX_VAL;
     ```

  3. const type* const var_name: Not allow to change both content and address

Const expression

-- function

- **Member function**: Declaring a member function with the const keyword specifies that the function is a "read-only" function that does not modify the object for which it is called

```
class Coordinate
{
private:
    int myX, myY;

public:
    int getX() const{
        myX = 2; // not work
        return myX;
    }
    void setX(int a){ my_X = a;}
}
```

```
void printX(const Coordinate& c){
    std::cout << c.getX() << std::endl;
}
```

Demo: https://github.com/aliciayuting/CS4414Demo.git

Const expression

-- function

- **Function Parameter**:
  - Passing by reference and by pointer , allow the function to avoid copying the variable
  - Using 'const' keyword for ref and pointer parameter will let the variable to be passed without copying but stop it from then being altered.

```
void Subroutine1(Coordinate a)
{ a.setX(3); }


void Subroutine2(Coordinate &a)
{ a.setX(3); }


void Subroutine2(Coordinate *a)
{ a->setX(3); }
```

```
void Subroutine2(Coordinate
const &a)
{ a.setX(3); }
```

✘ Compile error

```
void Subroutine2(Coordinate
const *a)
{ a->setX(3); }
```

✘ Compile error

?

Const expression

-- function

- **Function Return value**:
  - Misleading to use const for a return by value function

```
Const Coordinate Subroutine1(){
      // ……
}
```

✗ // when returning value, it creates a copy of the object and discard the const qualifier

Const expression

-- function

- **Function Return reference**:
  - We should return constant references only when are sure that the referenced object will be still available by the time we want to reference it.

```
void f() {
  MyObject o;
  const auto& aRef= o.getConstRef();
  aRef.doSomething();
}
```

// Depends on if the returned object can outlive the caller

Case1:

```
const T& MyObject::getSomethingConstRef() {
  T ret;
  // ...
  return ret; // ret destroyed after function}
```

Case2:

```
const T& MyObject::getSomethingConstRef() {
  return this->m_t;
// m_t lives with MyObject instance }
```

Const expression -- function

- **Function Return Pointer**:
  - Original function(left) is unsafe because the parameter is unprotected and the function can modify the elements of the array.
  - The second(right) partially safe function, because the function is unable to modify the array. But since the array is const in the function, it is illegal for a non-const pointer to point into the array

unsafe

```
int *find_largest3(int a[], int size)
{
   int i;
   int max = 0;
   for (i = 1; i < size; i++)
      if (a[i] > a[max])
         max = i;
   return &a[max];
}
```

Partially safe but illegal

```
int *find_largest3(const int a[], int size)
{
   int i;
   int max = 0;
   for (i = 1; i < size; i++)
      if (a[i] > a[max])
         max = i;
   return &a[max];
}
```

Const expression

-- function

- **Function Return Pointer**:
  - make both the parameter and return const

Safe and correct

```
const int *find_largest3(const int
a[], int size) {
   int i;
   int max = 0;
   for (i = 1; i < size; i++)
      if (a[i] > a[max])
         max = i;
   return &a[max];
}
```

Inline function

- Inline function is a C++ feature, that allows the compiler to replace the inline function definition wherever it is being called.
- Compiler replaces the definition of inline functions at compile time instead of referring function definition at runtime.
- It can reduce the function calling overhead each time when the function is being called by callers.

```
inline int add(int a, int b)
{
    return (a + b);
}

Result = add(3, 2);
```

Template

Template

--- motivation

- Templates are special functions that can operate with generic types.
- When functions perform the same logical operation, but on operands of different types.

```
void printVal(int value){
     std::cout << value << std::endl;
}

void printVal(std::string value){
     std::cout << value << std::endl;
}

     ……
```

```
Template <typename T>
void printVal(T value){
     // …
}
```

Template

--- how to use template

- Function template
- Class template

Template

--- Function template

- Function template parameters:
  - A template parameter list
  - A function parameter list
- Type parameter **T** is a placeholder for a type argument
- Function parameter value is a placeholder for argument expression

Template parameter list

```
Template <typename T>
void printVal(T value){
    std::cout << value << std::endl;
}
```

Function parameter list

Template

--- Function template

- A function template is not a function, but an algorithm(recipe) of how to generate a function
- The C++ compiler to automatically generate the code for a function

Function template:

```
Template <typename T>
void printVal(T value){
  std::cout<<value<<std::endl;
}
```

compiler

Template initiation:

```
int main(){
    printVal<int>(5);
}
```

Template

--- how to use template

- Function template
- Class template

Template

--- Class template

- Class template: a class can have fields and member functions that use template parameters as types.

```
template<typename T>
class fraction {
private:
     T num, denom;
public:
     fraction(){};
     fraction(T my_num, T my_denom);
     fraction &operator+=(fraction const &other);
};
```

Demo: https://github.com/aliciayuting/CS4414Demo.git

Template

--- Class template

- Class template: a class can have fields and member functions that use template parameters as types.
- Typename **T** only exist in the scope of the class template

```
template<typename T>
class fraction {
private:
 T num, denom;
public:
 fraction(T n, T d);
 fraction &operator+=
          (fraction const&other);
};
```

```
template<typename T>
fraction<T> &
fraction<T>::operator+=(fraction
const &other){
     // …. function content
}
```

Template

--- how to use template

- Template Parameters:
  - Types
    - std::vector<int> myVec;
    - std::map<std::string, int> myMap;
  - Non-Types
    - Integer value. // std::array<int, 3> myArray{1, 2, 3};
    - Pointers
    - …

Template

--- alias template

- Type alias(using keyword): a name reference to a defined type.

```
using byte       = unsigned char;         // use it by :  byte b {42};
using float_frac = fraction<float>;       // use it by float_frac a(3.0, 4.0);
```

- Alias template: Alias templates provide a means to give a convenient name to a family of types. They are in the form of template<template-params-list> identifier = type-id

```
template <typename T, int Line, int Col>
  class Matrix{
               ....}
Template<typename T, int Line> using Square = Matrix<T, Line, Line>;
Matrix<int, 3, 4> ma;
Square<double, 4> sq;
```

Performance

Performance

- Performance measurement:
  - Bandwidth, latency

- Costs in modern system
  - Network delay
  - Locking delay
  - Pipelining
  - Hierarchy of data-accessing: data in register memory, in cache, in DRAM, in remote DRAM, storage devices
  - Algorithm efficiency

Performance

- How to know where does the program spend the time and understand bottleneck in my code?
  - Use profiling tools: linux tool, IOSTATE, VMSTATE, Htop, Perf, gprof (we will be using in assignment)
  - Gprof:
    - Linux kernel helps by using timers to build a histogram of where the PC pointed as the program executes.

```
Flat profile:

 %     cumulative self    self    total
 time   seconds   seconds calls ms/call ms/call name
 17.7    3.72      3.72 13786208 0.00    0.00    Ns_DStringNAppend [8]
  6.1    5.00      1.28   107276 0.01    0.03    MakePath [10]
  2.9    5.60      0.60  1555972 0.00    0.00    Ns_DStringFree [35]
  2.7    6.18      0.58  1555965 0.00    0.00    Ns_DStringInit [36]
  2.3    6.67      0.49  1507858 0.00    0.00    ns_realloc [40]
```

Performance

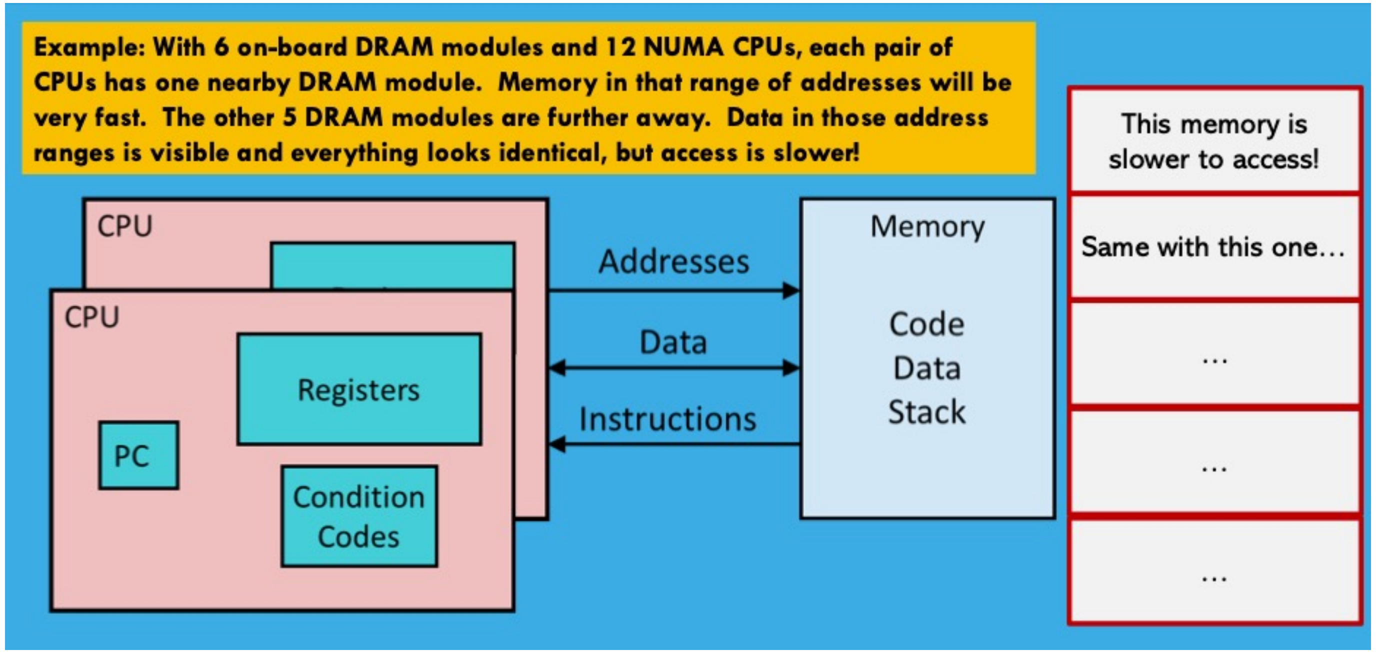
- How to know where does the program spend the time?
  - Use profiling tools: linux tool, IOSTATE, VMSTATE, Htop, Perf, gprof (we will be using in assignment)
  - Gprof:
    - Linux kernel helps by using timers to build a histogram of where the PC pointed as the program executes.
    - g++ -pg helps by including some additional method-call tracing data in a dedicated register.

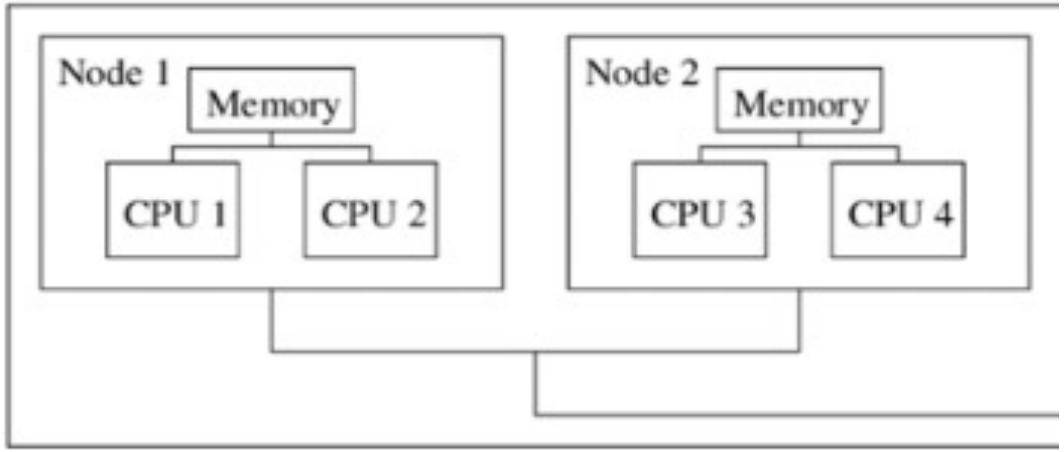
- How to detect memory leak?
  - Valgrind

System and Architecture

- Architecture
- Concurrency
- Linux
- Memory
- System Abstraction
- Exceptions

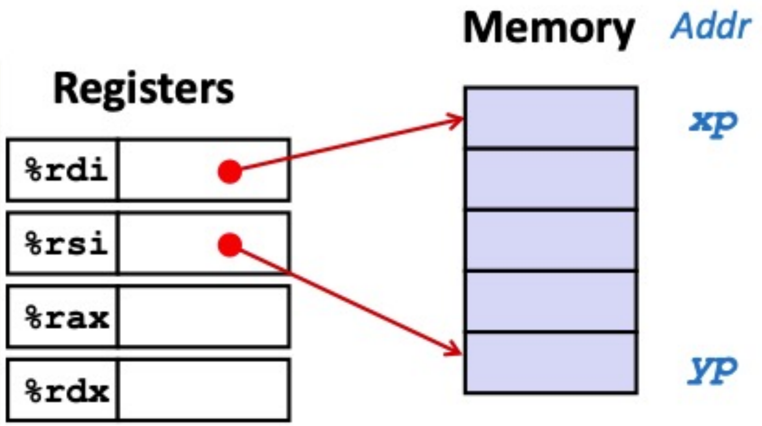
Architecture and Machine Language





Understanding swap()

```
void swap
   (long *xp, long *yp)
{
  long t0 = *xp;
  long t1 = *yp;
  *xp = t1;
  *yp = t0;
}
```

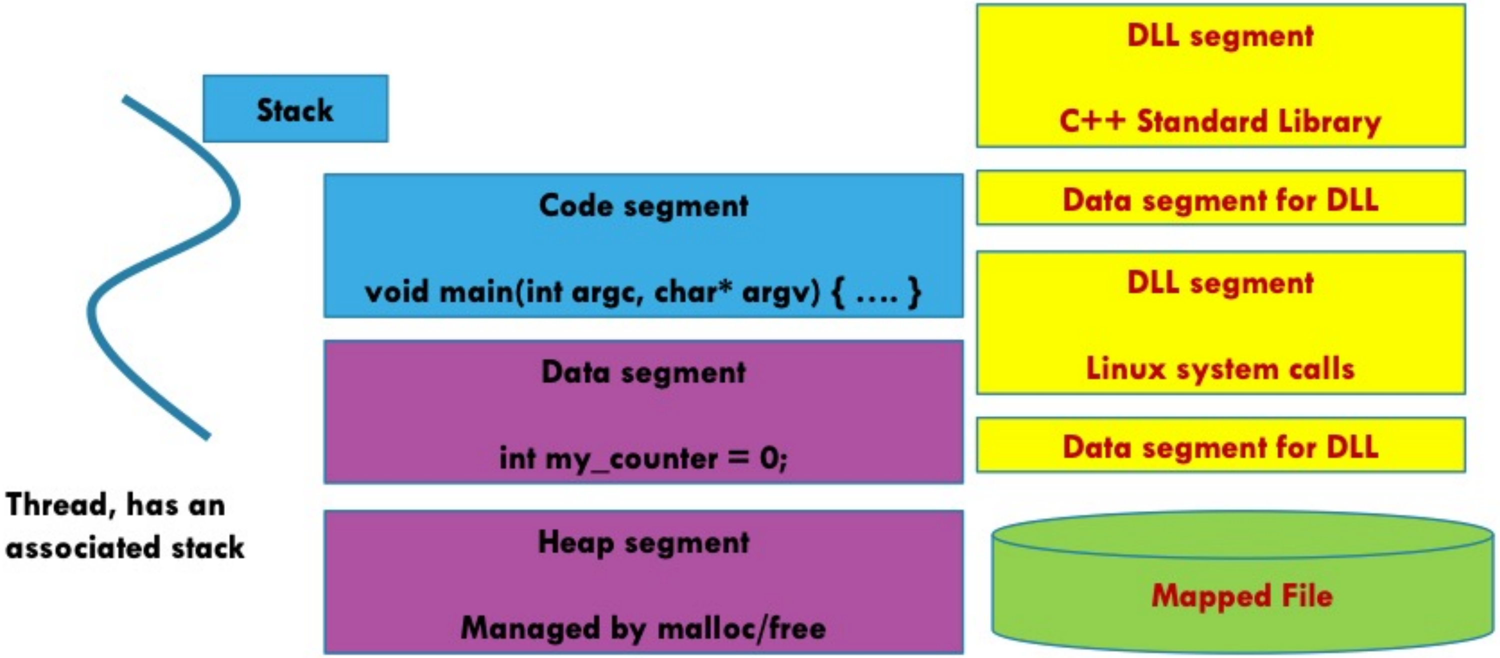


Register	Value
%rdi	xp
%rsi	yp
%rax	t0
%rdx	t1

```
swap:
   movq     (%rdi), %rax   # t0 = *xp
   movq     (%rsi), %rdx   # t1 = *yp
   movq     %rdx, (%rdi)   # *xp = t1
   movq     %rax, (%rsi)   # *yp = t0
   ret
```

Memory

- Segment types Linux supports
  - Code
  - Data
  - Stack and heap (refer to recitation5)
  - Mapped files

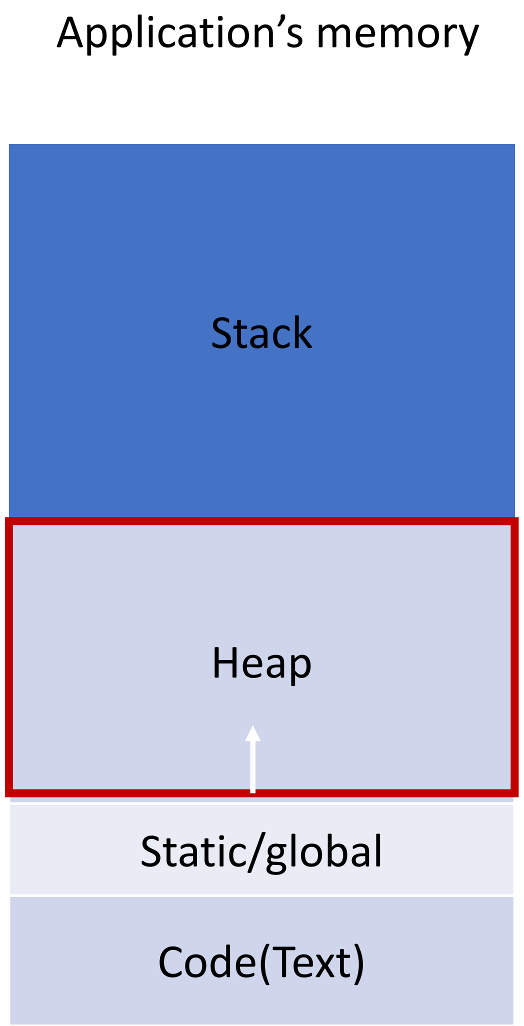


Memory

--- memory allocation

- Heap: A heap segment is used for dynamically allocated memory that will be used for longer periods

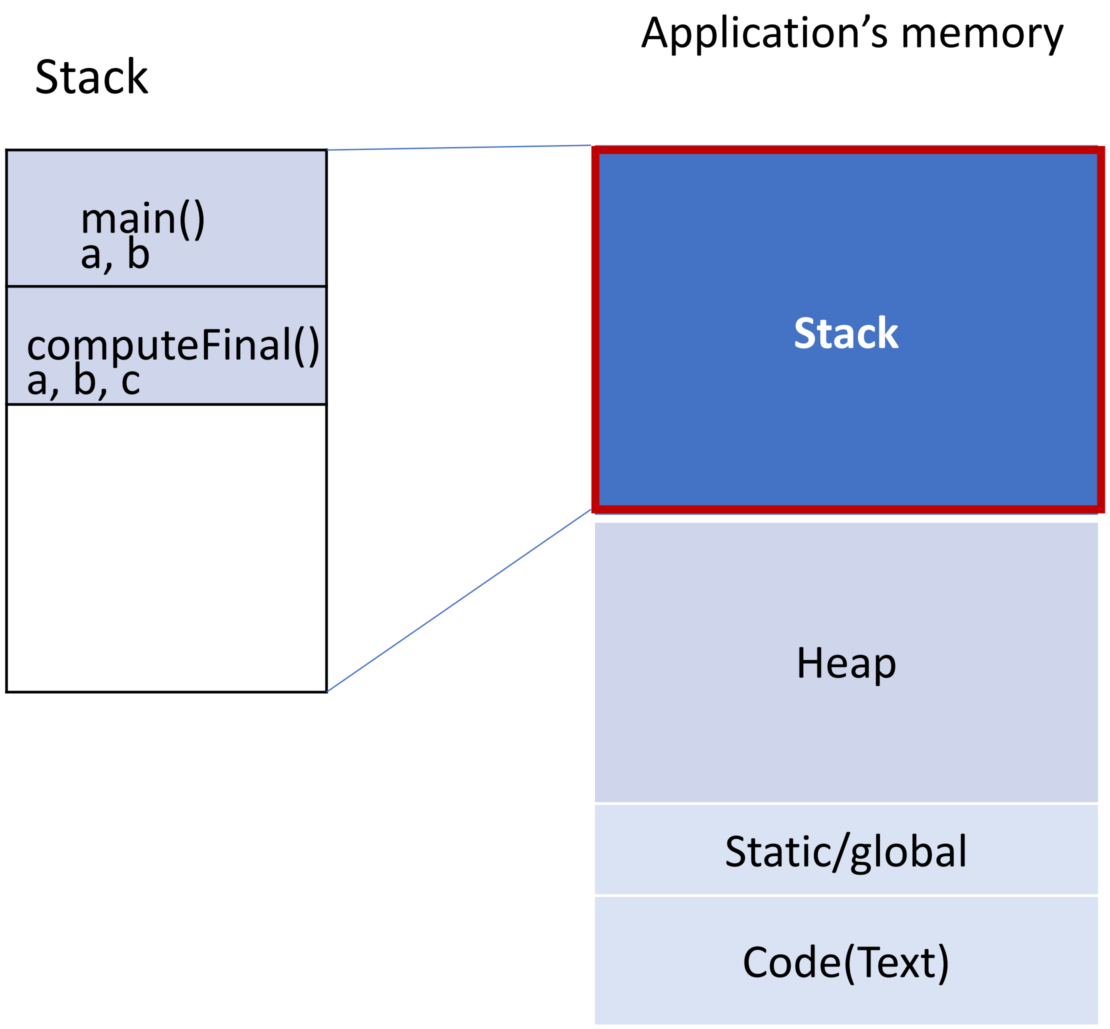
```
int computeA(int a){ return a*a; }

int computeFinal(int a, int b){
    int c = computeA(a) + b;
    return c;
}
const int{ 5};
int main()
{
    int *ptr  = new int[10];
    int a = 1, int b = 2;
    total = computeFinal(a, b);
    return toal;
}
```



Memory

--- stack and heap allocation

```
int computeA(int a){ return a*a; }

int computeFinal(int a, int b){
    int c = computeA(a) + b;
    return c;
}
const int MAX_VALUE{ 5};
int main()
{
    int *ptr  = new int[10];
    int a = 1, int b = 2;
    total = computeFinal(a, b);
    return toal;
}∂
```



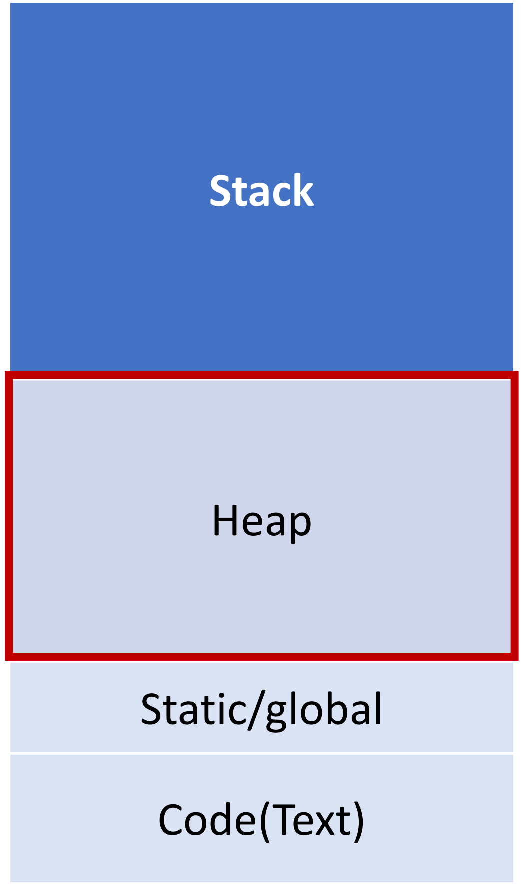
Memory

--- stack and heap allocation

- Code: This kind of segment holds compiled machine instructions

```
int computeA(int a){ return a*a; }

int computeFinal(int a, int b){
    int c = computeA(a) + b;
    return c;
}
const int MAX_VAL{ 5};
int main()
{
    int a = 1, int b = 2;
    total = computeFinal(a, b);
    return total;
}
```

Application's memory

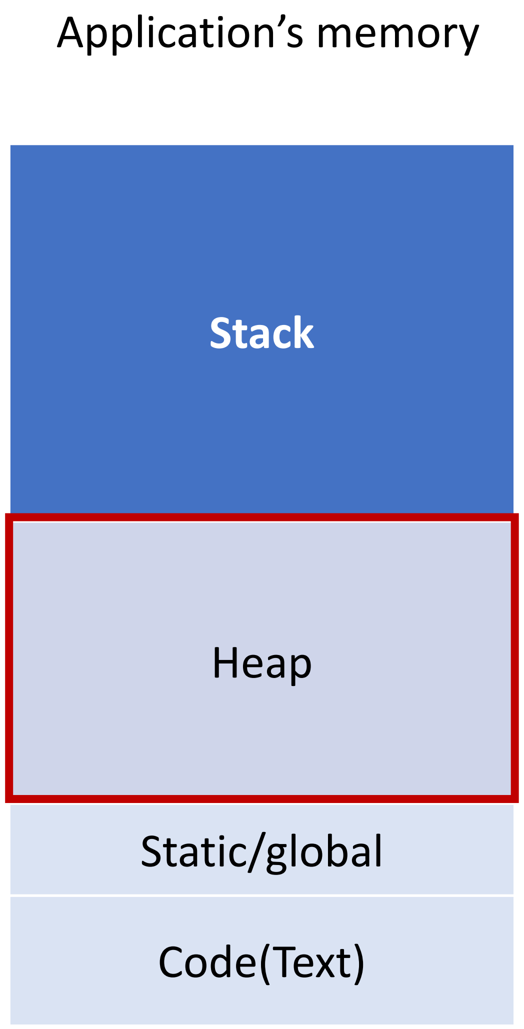


Memory

--- stack and heap allocation

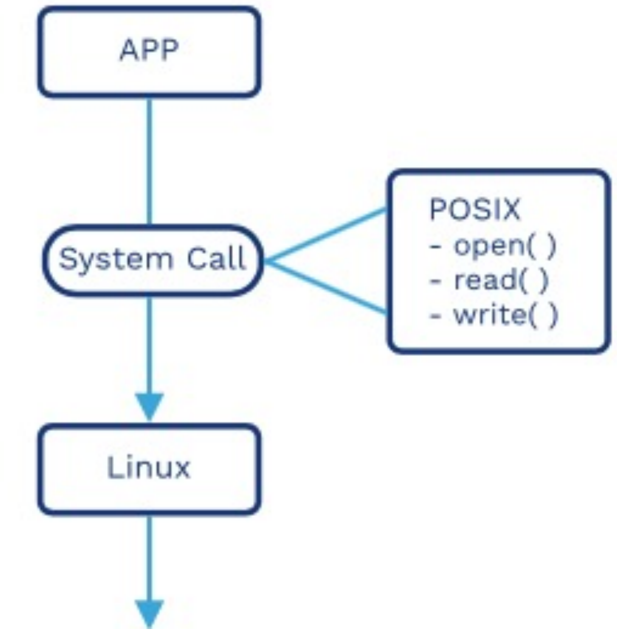
- Code: This kind of segment holds compiled machine instructions

```
int computeA(int a){ return a*a; }

int computeFinal(int a, int b){
    int c = computeA(a) + b;
    return c;
}

Const int MAX_VAL{ 5};
int main()
{
    int a = 1, int b = 2;
    total = computeFinal(a, b);
    return total;
}
```



System Abstraction

- File system:
  - POSIX (Portable Operating System Interface) is a family of standards created to make sure that applications developed on one UNIX can run on other UNIXes.
  - Posix file system is an interface for program to interact with the file system
- Virtualization
  - We can abstract a move applications
  - to a new environme



Linux

- On Linux, programs have three ways to discover runtime parameters that tell them what to do.
  - Arguments provided when you run the program, on the command line
  - Configuration files, specific to the program, that it can read to learn parameter settings, files to scan, etc.
  - Linux environment variables. (HOME, USER, PATH, PYTHONPATH) These are managed by bash and can be read by the program using “getenv” system calls.
- Files and permission
  - ls –l :   you can see rwx permission with owners, such as user group root

Concurrency

- Parallelism
  - Task level parallelism (Wordcount example)
  - Bottleneck:
    - Compute-bound (such as, critical path computation based on Amdahl law)
    - I/O bound (such as, File access cost)

Where to find the resources?

- Course lecture slides:

  https://www.cs.cornell.edu/courses/cs4414/2021fa/Schedule.htm

- C++ tutorials:
  - https://www.youtube.com/watch?v=LMP_sxOaz6g
  - https://subscription.packtpub.com/book/programming/9781786465184/1/ch01lvl1sec6/creating-type-aliases-and-alias-templates