Lecture 17: Context Switching Inside the User Space

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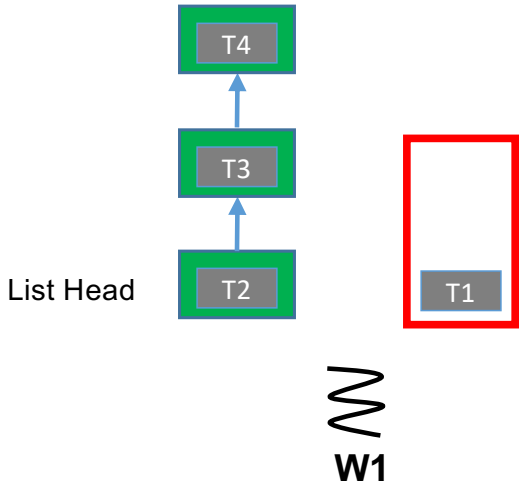
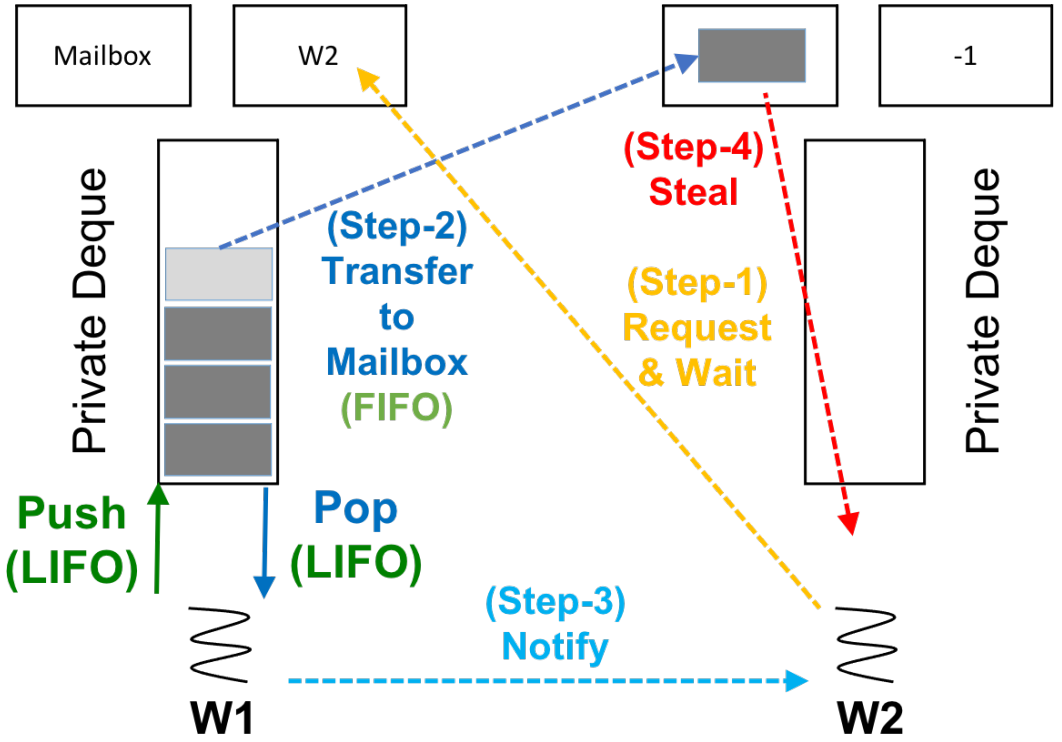
Last Lecture (Recap)





- Minimizing deque overheads
  - Using a mix of list and deque
  - Using private deque

Today's Class

- More about thread
  - Stack
- Boost C++ libraries for concurrency
  - Context
- CPU scheduling

Callee and Caller

```
L1: main () {

L2:   bar(100);

L3: }
```

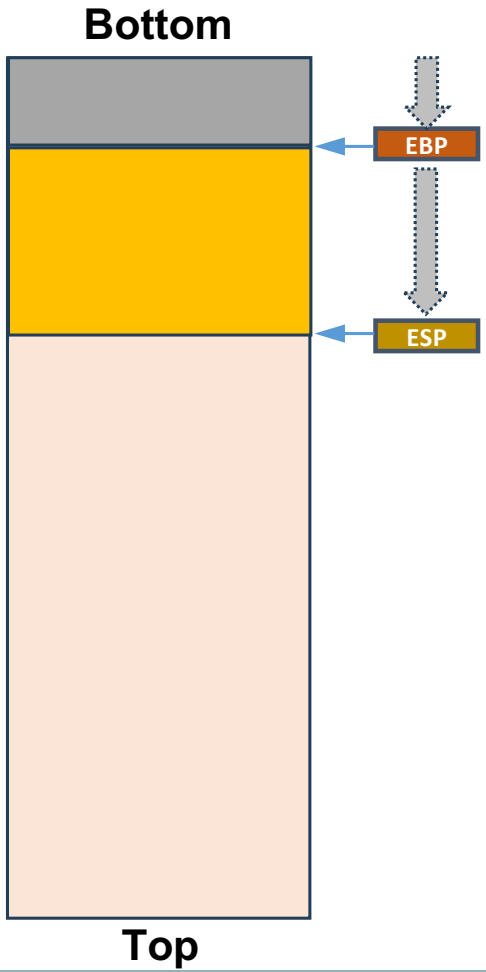
```
L4: bar(int x) {

L5:   int b1=x1;

L6: }
```

- Call chain
  - main → bar
- Callee and Caller
  - main (caller) → bar (callee)

Thread Stack Frames in X86

```
L1: main () {

L2:   bar(100);

L3: }
```

```
L4: bar(int x) {

L5:   int b1=x1;

L6: }
```

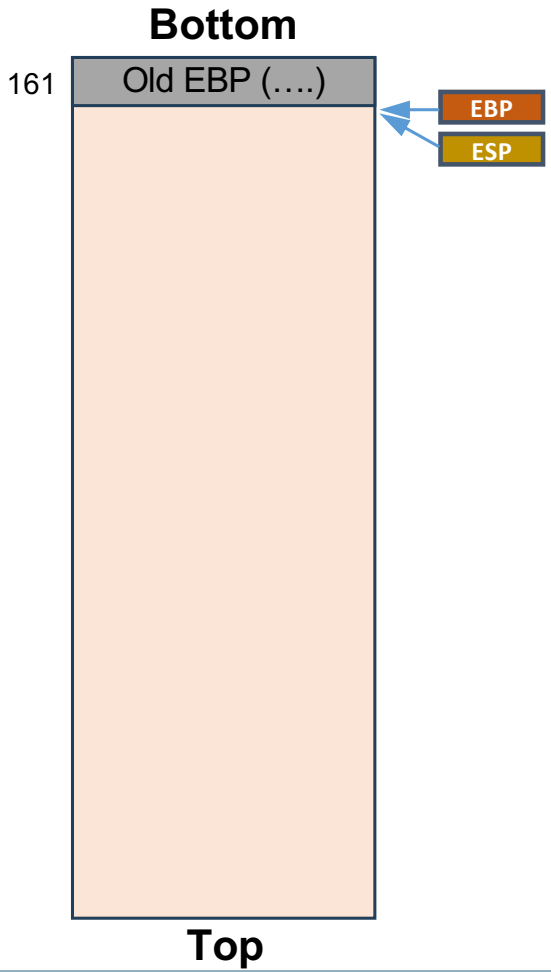


- **EBP** register points to **bottom** of the stack (first item pushed on the stack) and **ESP** register points to the **top** of the stack (last item pushed on stack)
- Area of the stack between the location pointed by EBP and ESP is called **stack frames** for that method
- The **topmost frame** corresponds to the currently executing method

Thread Stack in X86 (1/7)

```
L1: main () {
      <save_regs>

L2:   bar(100);


L3: }
```

```
L4: bar(int x) {

L5:   int b1=x1;

L6: }
```

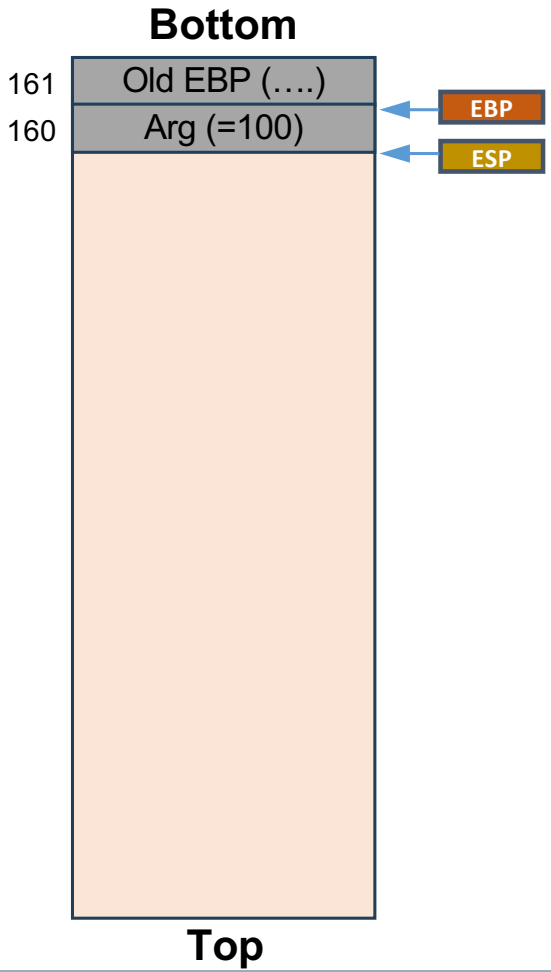


- <save regs>
  - Current content of EBP register is saved in stack
    - Carried out before every method call
    - Also known as **method prologue**
  - EBP now points to the slot containing old value of EBP
  - ESP also points to the same slot

Thread Stack in X86 (2/7)

```
L1: main () {
      <save_regs>
      <alloc(4)>

L2:   bar(100);



L3: }
```

```
L4: bar(int x) {


L5:   int b1=x1;


L6: }
```

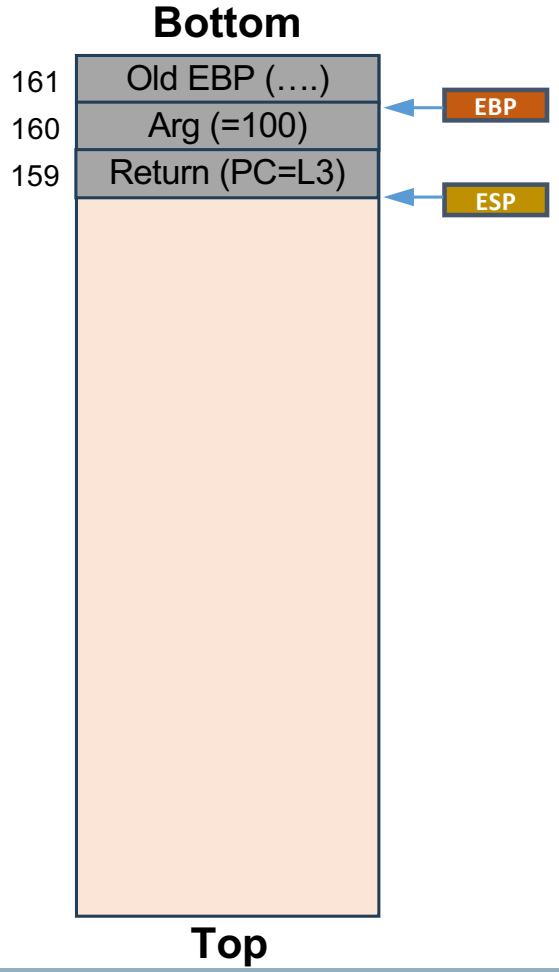


- <alloc(4)>
  - One slot is added on the stack in the current stack frame for the argument to the callee method
  - ESP is updated

Thread Stack in X86 (3/7)

```
L1: main () {
        <save_regs>
        <alloc(4)>
        <save(PC)>
L2:   bar(100);



L3: }
```

```
L4: bar(int x) {


L5:   int b1=x1;


L6: }
```

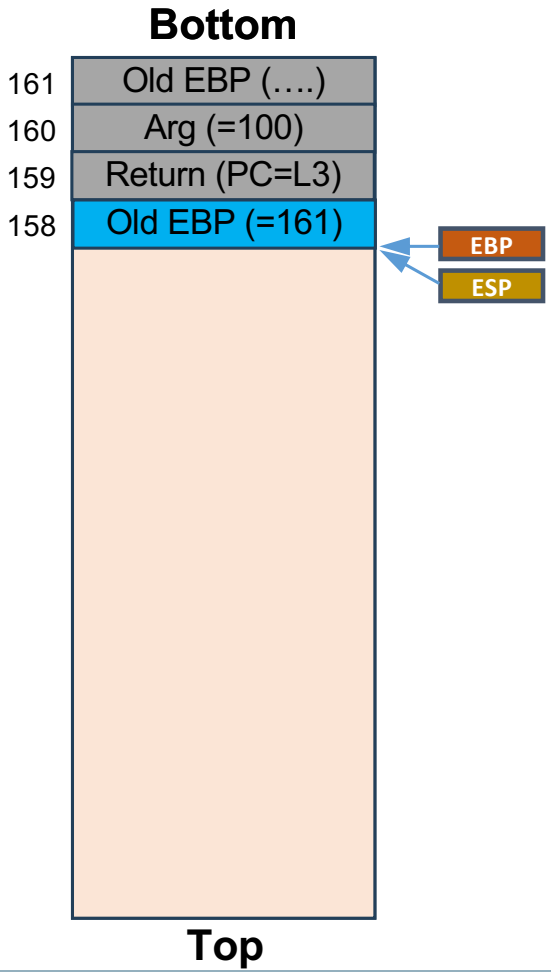


- <save (PC)>
  - Current content of **EIP** register is saved in stack
  - ESP is now pointing to newly added slot

Thread Stack in X86 (4/7)

```
L1: main () {
        <save_regs>
        <alloc(4)>
        <save(PC)>
L2:     bar(100);



L3: }
```

```
L4: bar(int x) {
        <save_regs>

L5:     int b1=x1;


L6: }
```

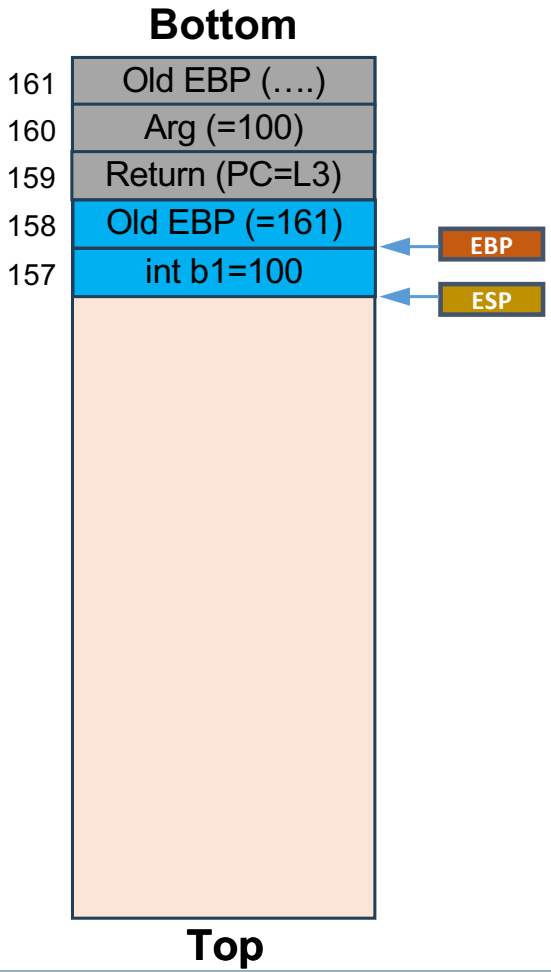


- <save regs>
  - Context switch!
  - Current content of EBP register is saved in stack
  - EBP now points to the slot containing old value of EBP
  - ESP also points to the same slot

Thread Stack in X86 (5/7)

```
L1: main () {
        <save_regs>
        <alloc(4)>
        <save(PC)>
L2:   bar(100);


L3: }
```

```
L4: bar(int x) {
        <save_regs>
        <alloc(4)>
L5:   int b1=x1;


L6: }
```

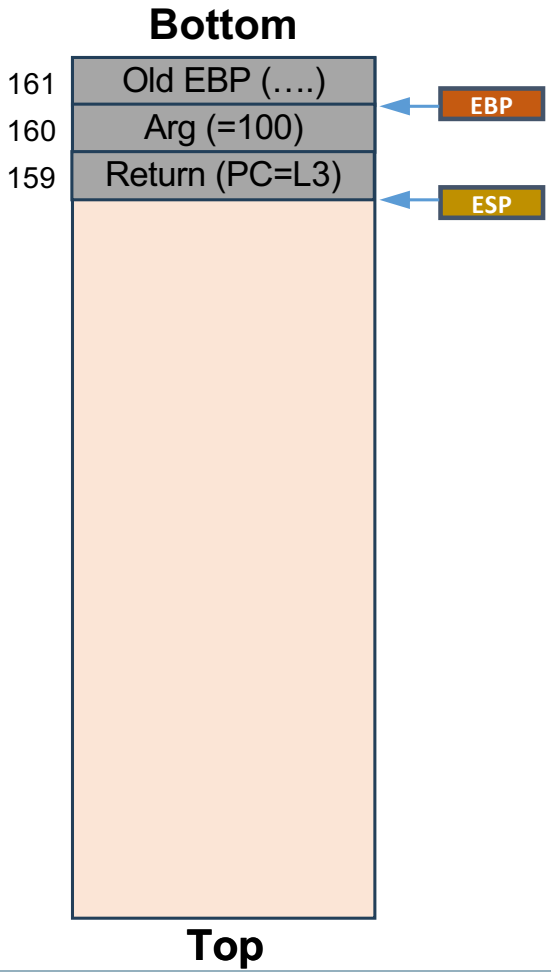


- <alloc(4)>
  - One slot is added on the stack in the current stack frame for the local variable
  - ESP is updated

Thread Stack in X86 (6/7)

```
L1: main () {
        <save_regs>
        <alloc(4)>
        <save(PC)>
L2:     bar(100);



L3: }
```

```
L4: bar(int x) {
        <save_regs>
        <alloc(4)>
L5:     int b1=x1;
        <dealloc(4)>
        <restore_regs>
L6: }
```

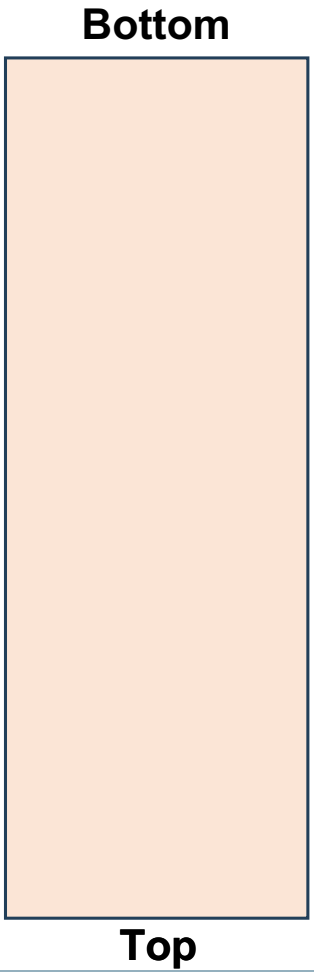


- <dealloc(4)>
  - ESP is updated to point to the slot just before the slot(s) added for storing local variable(s)
- <restore_regs>
  - Old value of EBP is popped and stored in EBP
  - ESP adjusted to point to the last slot in the current stack frame

Thread Stack in X86 (7/7)

```
L1: main () {
        <save_regs>
        <alloc(4)>
        <save(PC)>
L2:     bar(100);
        <restore(PC)>
        <dealloc(4)>
        <restore_regs>
L3: }
```

```
L4: bar(int x) {
        <save_regs>
        <alloc(4)>
L5:     int b1=x1;
        <dealloc(4)>
        <restore_regs>
L6: }
```



- <restore(PC)>
  - EIP register is now restored with the old value of EIP before the call went inside the callee
    - Context switch!
- <dealloc(4)>
  - ESP is updated to point to the slot just before the slot(s) added for storing local variable(s)
- <restore_regs>
  - Old value of EBP is popped and stored in EBP
  - ESP adjusted to point to the last slot in the current stack frame
    - Context switch!

Today's Class

- More about thread
  - Stack
- Boost C++ libraries for concurrency
  - Context
- CPU scheduling

Is it Possible in Plain C/C++?

```
void A() {
  cout<< “IN-A” << endl;
  /* Do something */
  cout<< “OUT-A” << endl;
}
void B() {
  cout<< “IN-B” << endl;
  /* Do something */
  cout<< “OUT-B” << endl;
}
void C() {
  cout<< “IN-C” << endl;
  /* Do something */
  cout<< “OUT-C” << endl;
}
int main() {
  A();
  B();
  C();
}
```

Figure-1

- Output in Figure-1?

IN-A
OUT-A
IN-B
OUT-B
IN-C
OUT-C

- How to get this?

IN-A
IN-B
IN-C
OUT-A
OUT-B
OUT-C

Boost C++ Libraries

WELCOME TO BOOST.ORG!

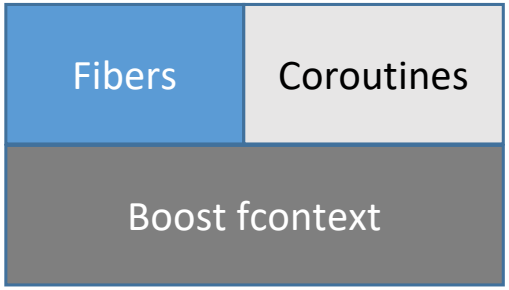
Boost provides free peer-reviewed portable C++ source libraries.

We emphasize libraries that work well with the C++ Standard Library. Boost libraries are intended to be widely useful, and usable across a broad spectrum of applications. The Boost license encourages the use of Boost libraries for all users with minimal restrictions.

We aim to establish "existing practice" and provide reference implementations so that Boost libraries are suitable for eventual standardization. Beginning with the ten Boost Libraries included in the Library Technical Report (TR1) and continuing with every release of the ISO standard for C++ since 2011, the C++ Standards Committee has continued to rely on Boost as a valuable source for additions to the Standard C++ Library.

Boost Context Library

- Provides a sort of cooperative multitasking on a single thread
- By providing an abstraction of the current execution state in the current thread, a *fcontext_t* instance represents a specific point in the application's execution path
  - stack (with local variables)
  - stack pointer
  - all registers and CPU flags
  - instruction pointer
- Provides the means to suspend the current execution path and to transfer execution control, thereby permitting another *fcontext_t* to run on the current thread
  - Helps in extremely low latency context switching of execution inside userspace (around 19 CPU cycles on x86_64 platform [1])
- Disadvantage
  - Not supported on all platforms as based on assembly code



Documentation: https://www.boost.org/doc/libs/1_80_0/libs/context/doc/html/index.html

[1] https://www.boost.org/doc/libs/1_80_0/libs/context/doc/html/context/performance.html#performance

Boost Context C++11 Library: Boost Context: Only Two Low-level Core APIs

```
1. void foo() {
2.   S1;
3.   //continuation of S1 (L4+)
4.   S2;
5.   //continuation of S2 (L6+)
6.   S3;
7. }
```

- Two primary operations
  - callcc
    - Create new context (stack)
      - *On my system, the default size of the stack being created was 128Kb*
    - Call with current **continuation**
      - Captures current continuation and triggers a context switch
  - Resuming a saved continuation
    - resume()
      - Can be used to switch across different continuations

Boost Context C++11 Library: Example

```
void A() {
  cout<< “IN-A” << endl;
  /* Do something */
  cout<< “OUT-A” << endl;
}
void B() {
  cout<< “IN-B” << endl;
  /* Do something */
  cout<< “OUT-B” << endl;
}
void C() {
  cout<< “IN-C” << endl;
  /* Do something */
  cout<< “OUT-C” << endl;
}
int main() {
  A();
  B();
  C();
}
```

Figure-1

```
#include <boost/context/all.hpp>
ctx::continuation A(ctx::continuation cont) {
  cout<< “IN-A” << endl;
  cont = cont.resume();
  /* Do something */
  cout<< “OUT-A” << endl;
  return std::move(cont);
}
/* Methods B & C rewritten as A above */
int main() {
  ctx::continuation a = ctx::callcc(A);
  ctx::continuation b = ctx::callcc(B);
  ctx::continuation c = ctx::callcc(C);
  a.resume();
  b.resume();
  c.resume();
}
```

Figure-2

Used to switch across different continuations

Call with current continuation. Captures current continuation and triggers a context switch

- Figure-1

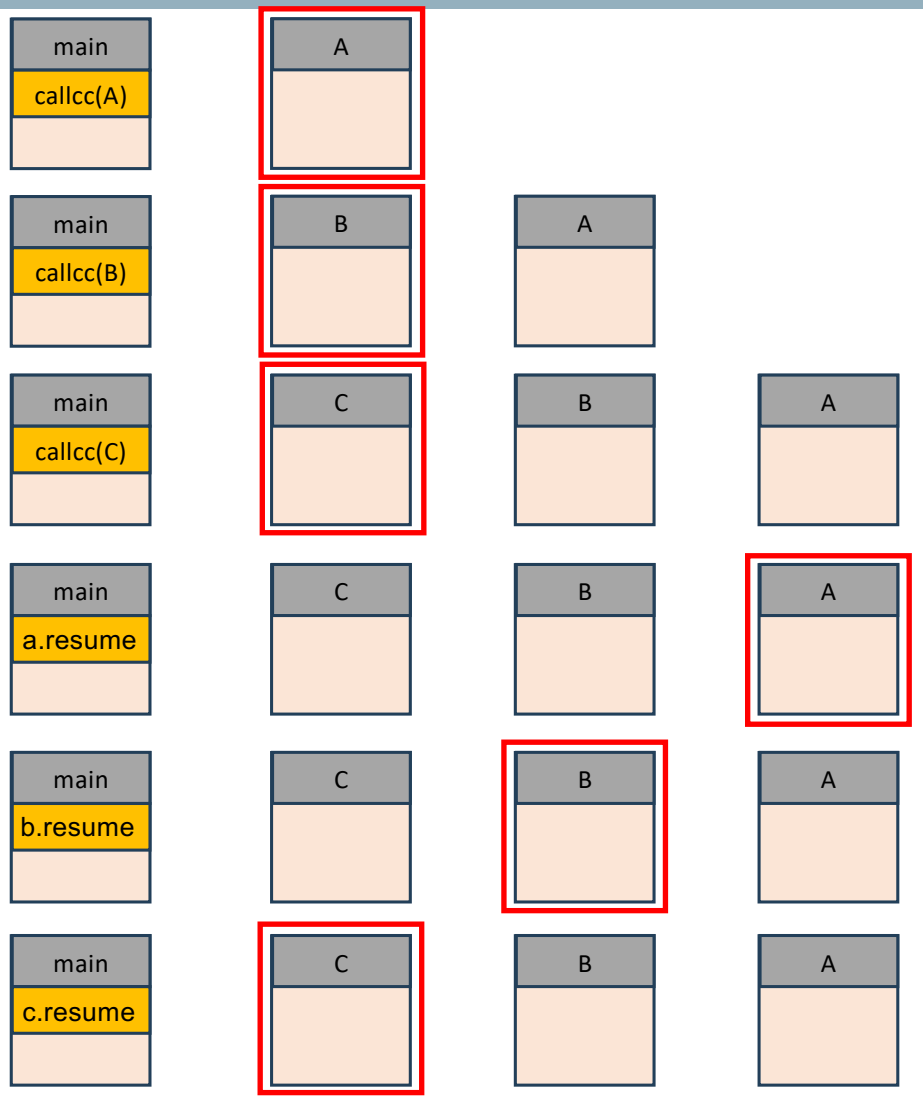
IN-A
OUT-A
IN-B
OUT-B
IN-C
OUT-C

- Figure-2

IN-A
IN-B
IN-C
OUT-A
OUT-B
OUT-C

Boost Context C++11 Library: Stack Switch

```
#include <boost/context/all.hpp>
ctx::continuation A(ctx::continuation cont) {
  cout<< "IN-A" << endl;
  cont = cont.resume();
  /* Do something */
  cout<< "OUT-A" << endl;
  return std::move(cont);
}
/* Methods B & C rewritten as A above */
int main() {
  ctx::continuation a = ctx::callcc(A);
  ctx::continuation b = ctx::callcc(B);
  ctx::continuation c = ctx::callcc(C);
  a.resume();
  b.resume();
  c.resume();
}
```



Another Example, Output?

```
int main() {
  int counter = 1;
  ctx::continuation c = ctx::callcc([&](ctx::continuation && c) {
    counter += 1;
    c = c.resume();
    counter -= 1;
    return std::move(c);
  });

  counter += 1;
  c = c.resume();
  std::cout <<”Counter = “ << counter;
  return 0;
}
```

Producer / Consumer Example

```
int available = false, data = 0;
ctx::continuation consumer(ctx::continuation && c) {
  while(true) {
     if(available == true) {
        printf("Consumer: Data = %d\n", data);
        available = false;
     } else {
        c = c.resume();
     }
  }
  return std::move(c);
}
int main() {
  int times = 0;
  ctx::continuation c = ctx::callcc(consumer);
  while(true) {
     if(available == false) {
        printf("Producer: Data = %d\n", ++data);
        available = true;
        times++;
     } else {
        c = c.resume();
        if(times == 5) break;
     }
  }
  return 0;
}
```

- Producer and consumer program
  - Without using multithreading!
- Consumer routine
  - Loop endlessly until data is available
  - Consume data if available
- Producer routine
  - Loop endlessly until data is available
  - Produce data if unavailable
- Total 5 data to be produced and consumed

Handling Blocking Task in plain C++

```
/* User application (C++11) */
.......
void main() {
  future_t* future = async([=]() {
      foo();
  });
  future.get();
}
```

```
/* Runtime implementation */
get() {
  if(this_future->not_ready()) {
    /* create/save current continuation and context
       switch to do something else */
  }
  else return this_future->value;
}
```

- Solution
  - Use boost context library (C++11) to avoid thread creation for any situation where the current thread cannot proceed due to blocking condition
  - Save the current context (continuation) and swap it with another ready context on the same thread

Installing Boost Context and Fiber Library

- Install Boost
  - wget https://boostorg.jfrog.io/artifactory/main/release/1.80.0/source/boost_1_80_0.tar.gz
  - tar xvfz boost_1_80_0.tar.gz
  - cd ~/boost_1_80_0/
  - ./bootstrap.sh --prefix=/absolute/path/to/boost-install --with-libraries=fiber,context
  - ./b2 install
- Compile programs
  - g++ -O3 -I/absolute/path/to/boost-install/include -L/absolute/path/to/boost-install/lib Program.cpp –lboost_fiber –lboost_context -lpthread
- Execute programs
  - export LD_LIBRARY_PATH=/absolute/path/to/boost-install/lib:$LD_LIBRARY_PATH
  - ./a.out

Reading Materials

- Context
  - https://www.boost.org/doc/libs/1_80_0/libs/context/doc/html/index.html

Next Lecture

- User level threads
- Quiz-4
  - Syllabus Lecture 13, 15-17