Real-time Systems SMD138

Lecture 4:

The inner workings of a kernel

(Burns/Wellings ch 7.3.1 only)

Scope

- To demystify the concept of "concurrent" execution on a sequential processor
- To provide initial help with lab assignment 2
- To set the scene for our forthcoming model of reactive concurrent programming

The infamous goto

```
A;
while (1) {
    B;
    if (e) goto label;
    C;
}
label:
D;
```

Classic code

```
A;
while (1) {
    B;
    if (e) break;
    C;
}
D;
```

Equivalent code,
structured programming

Non-local goto?

```
    A;
    while (1) {
        fun();
    }
label:
    D;
...

void fun() {
    int x[1000];
    B;
    if (e) goto label;
    C;
}
```

Can't jump to invisible label

```
    A;
    while (1) {
        try fun();
        catch(E) break;
    }
    D;
...

void fun() {
    int x[1000];
    B;
    if (e) throw(E);
    C;
}
```

Can't just leave x on stack

Note: Java/C++ code - not valid in C

A non-local goto!

```
A;
while (1) {
    if (setjmp(bf)) break;
    fun();
}
D;
```

Defines label "bf"

```
#include <setjmp.h>

jmp_buf bf;
```

```
void fun() {
    int x[1000];
    B;
    if (e) longjmp(bf, 1);
    C;
}
```

Jums to label "bf"

Setjmp/longjmp

- Save context (code-pointer and stack-pointer) in buf, then return 0

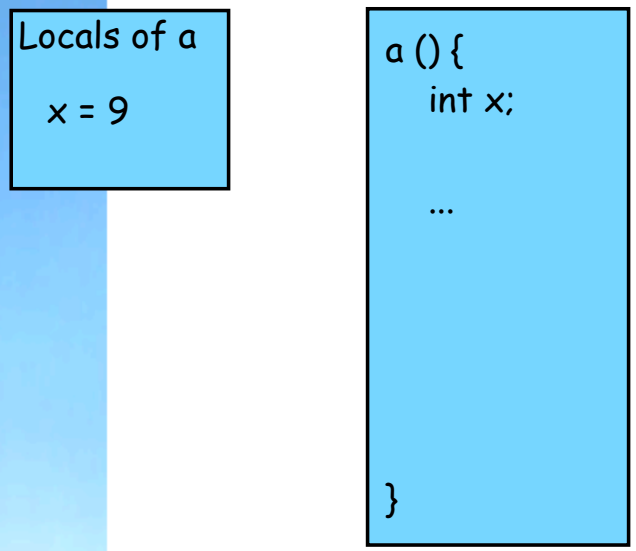
  setjmp(buf);

- Load context from buf, then return n

  longjmp(buf, n);

- Note: longjmp() returns its value after the registers have been restored; it will thus look as if it is setjmp() that returns n
- Note 2: a jmp_buf is known to be an array – no & operator needed

Ordinary function calls



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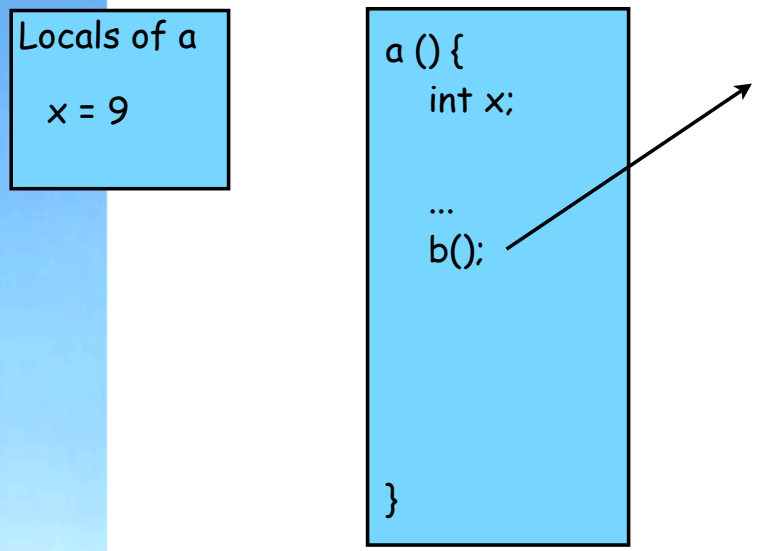

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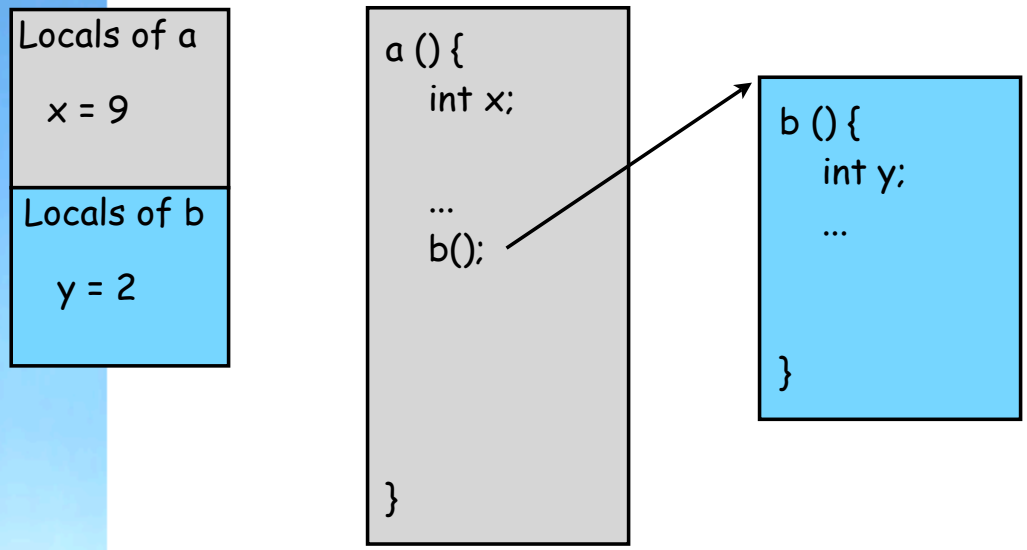

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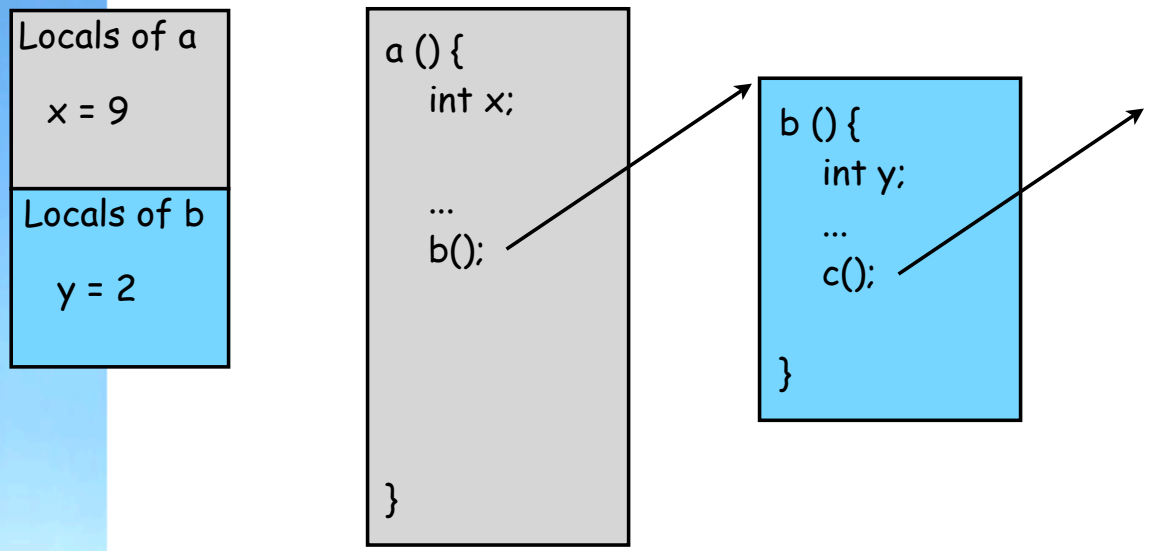

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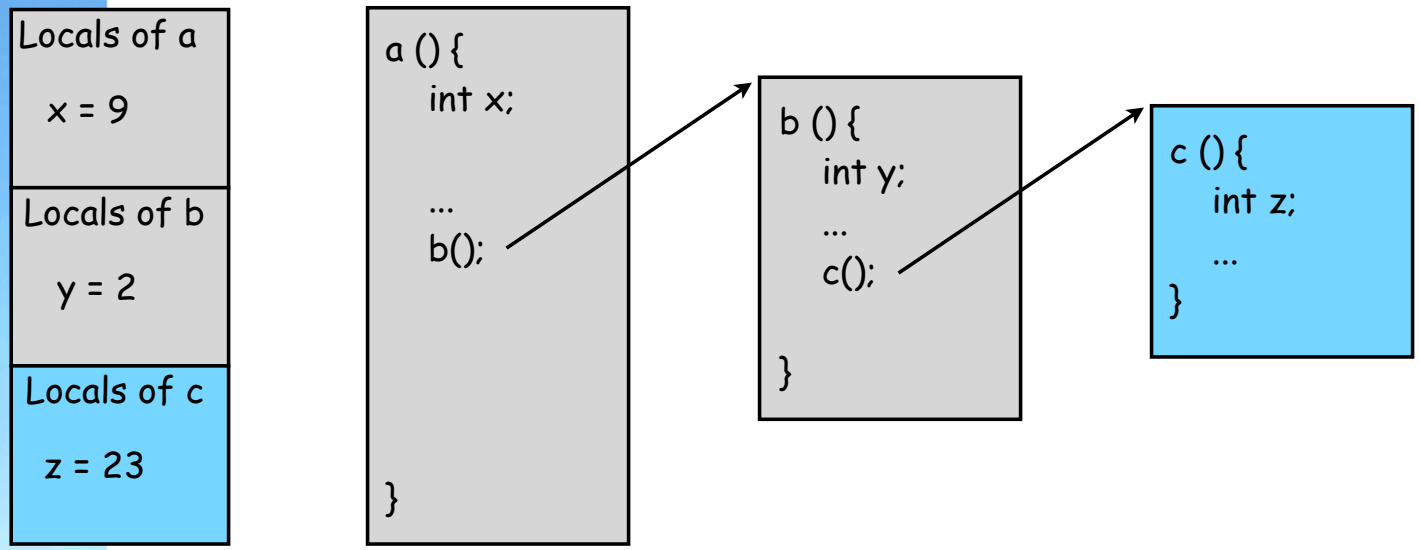

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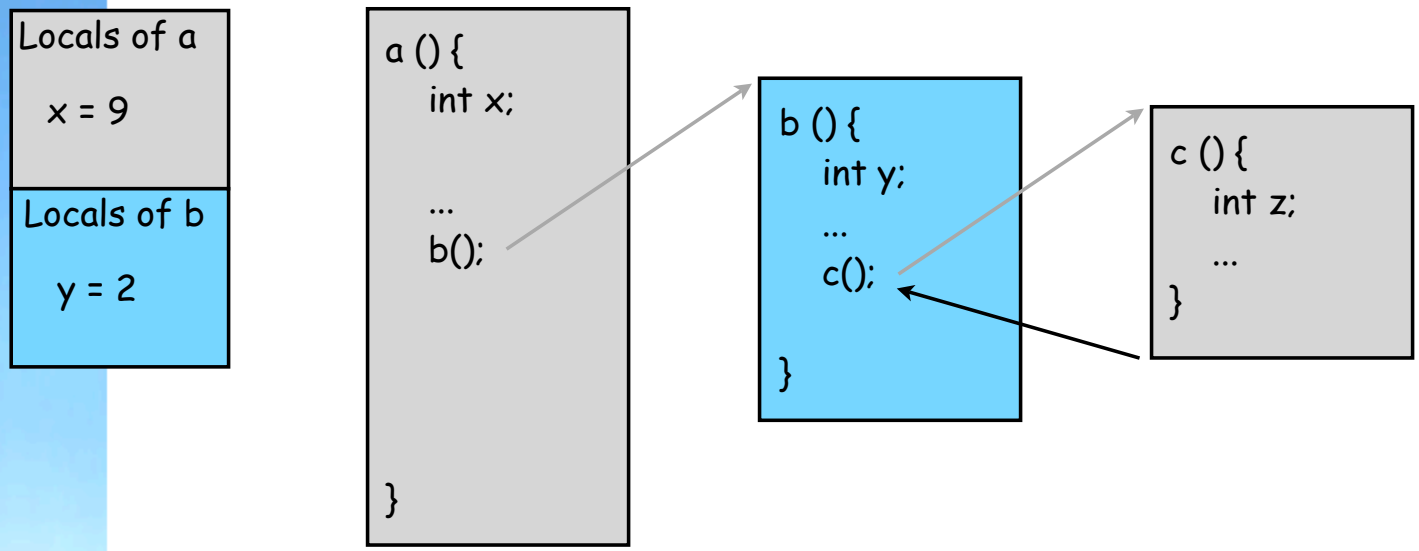

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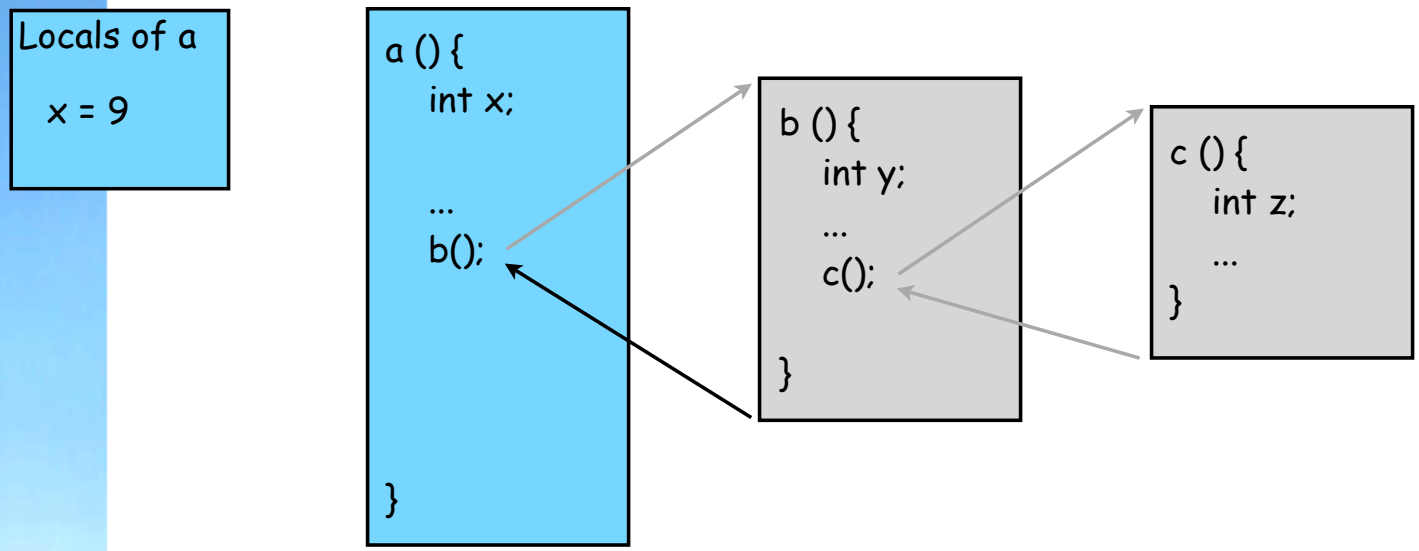
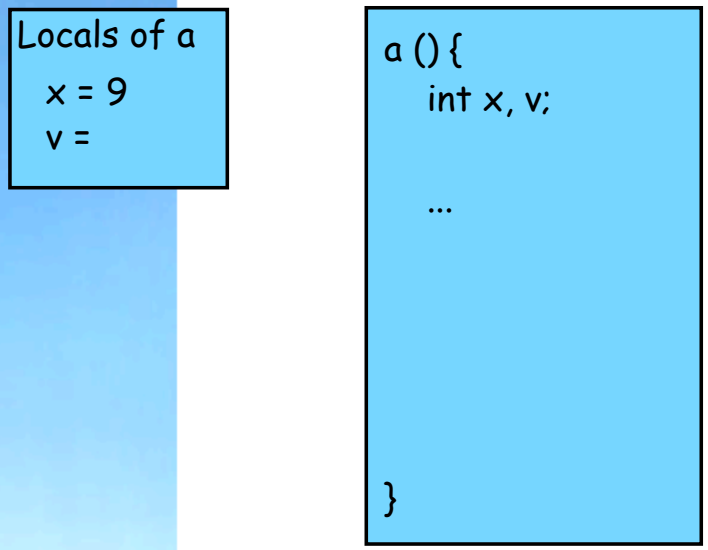


Using setjmp/longjmp

jmp_buf buf;



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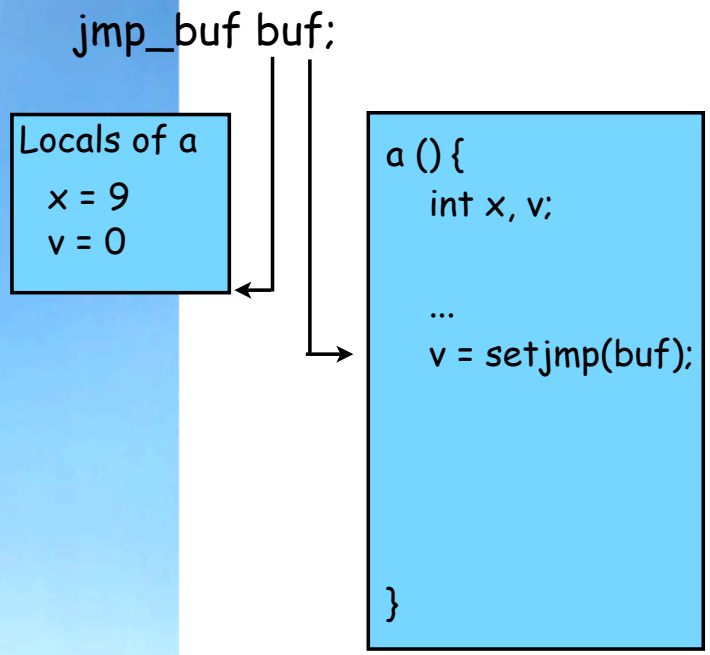

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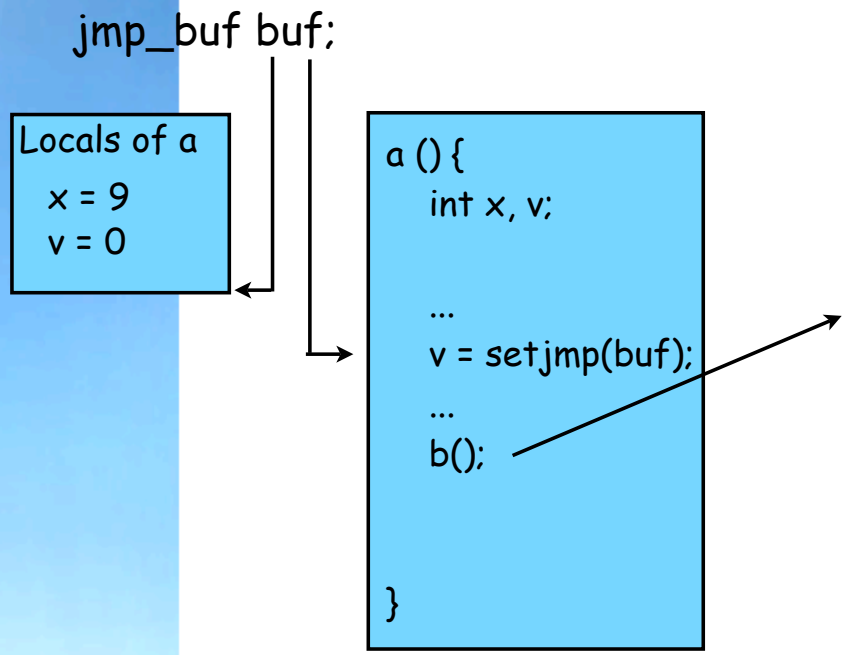

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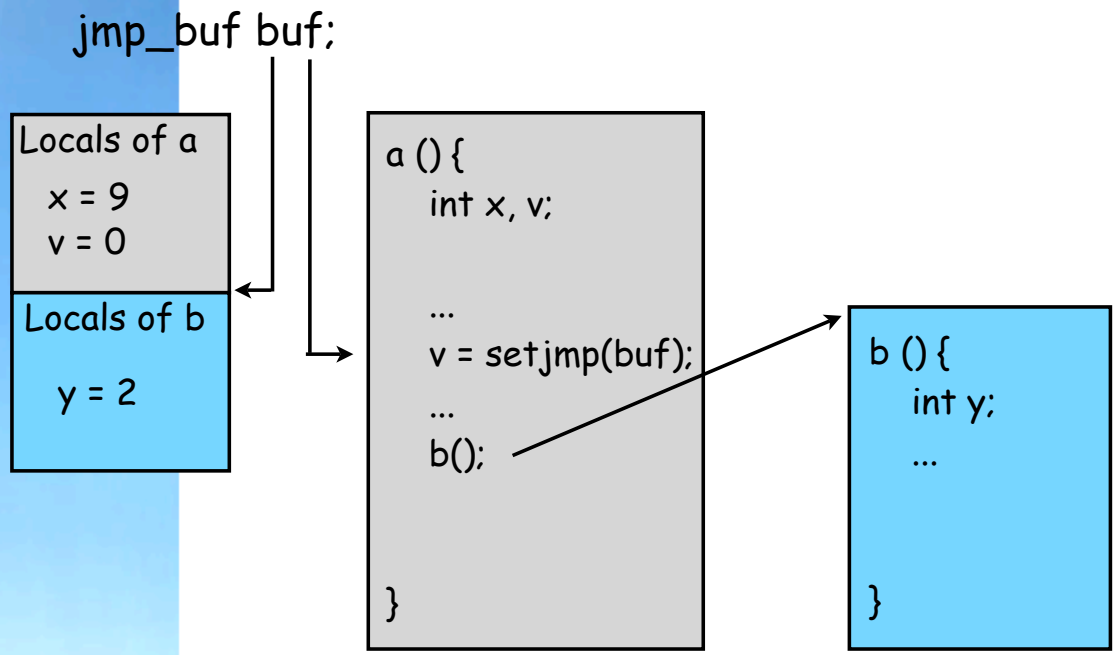

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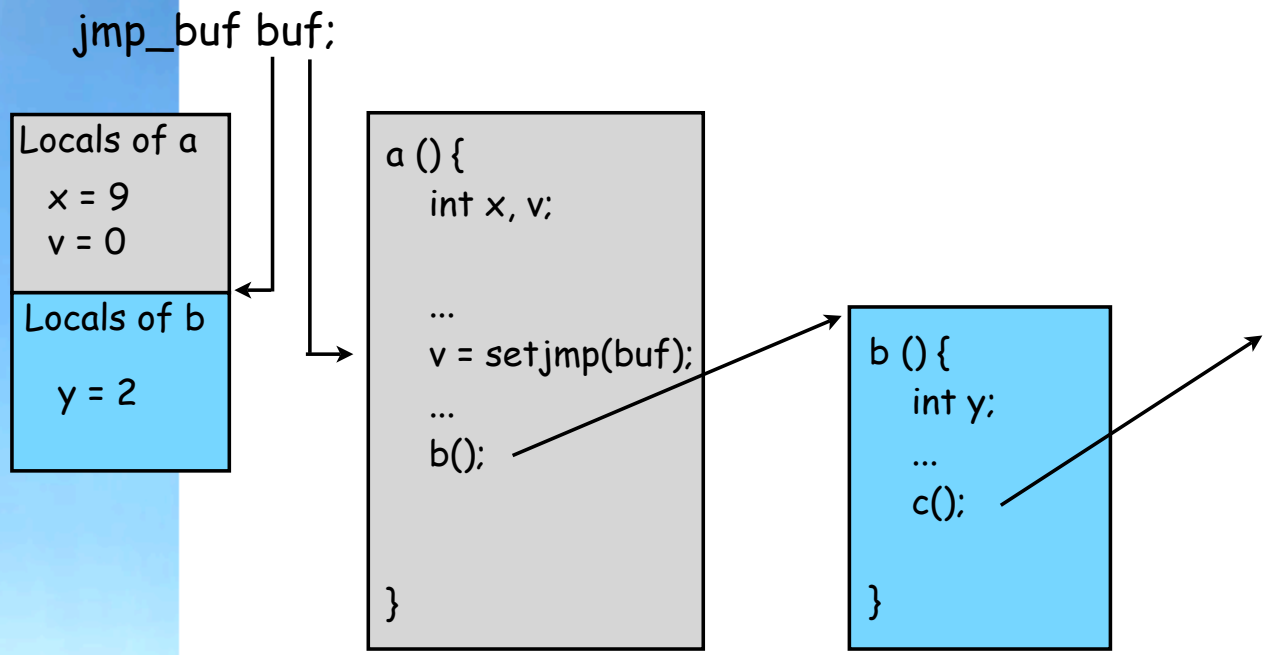

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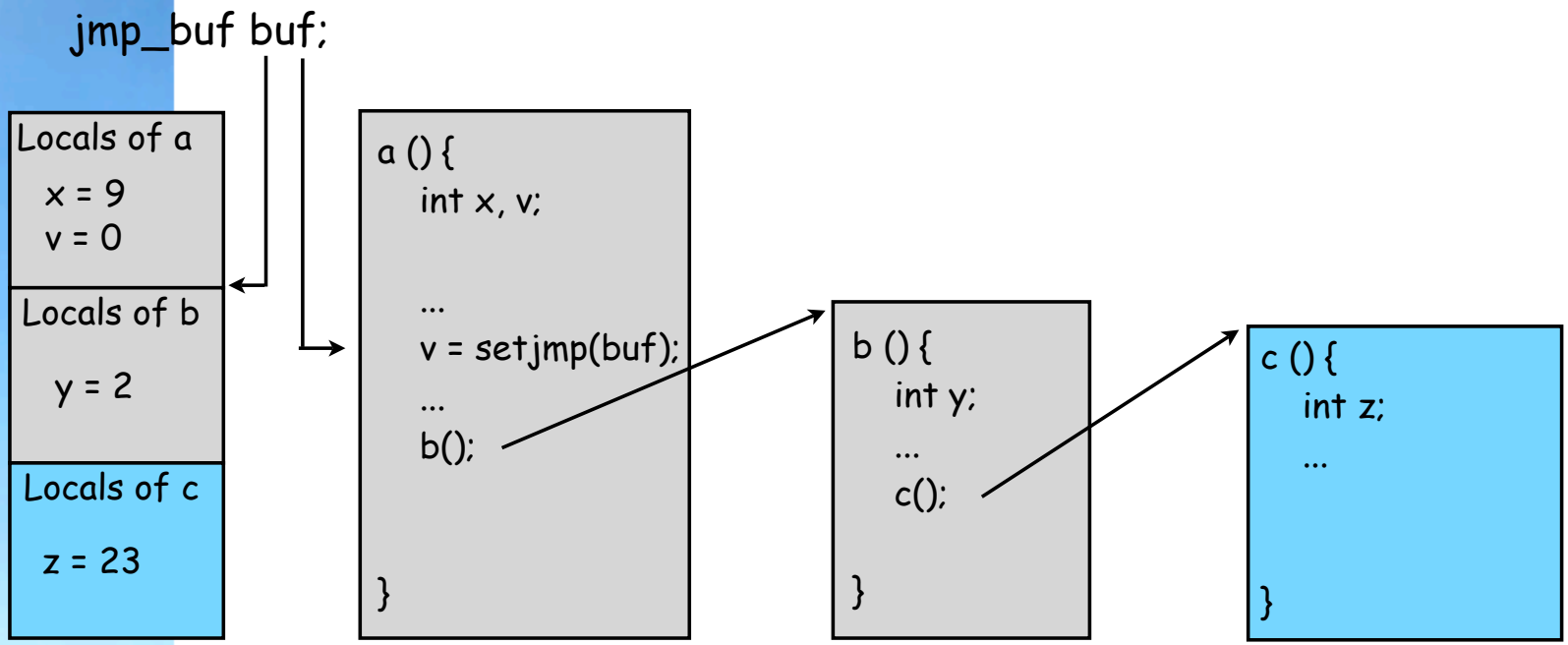

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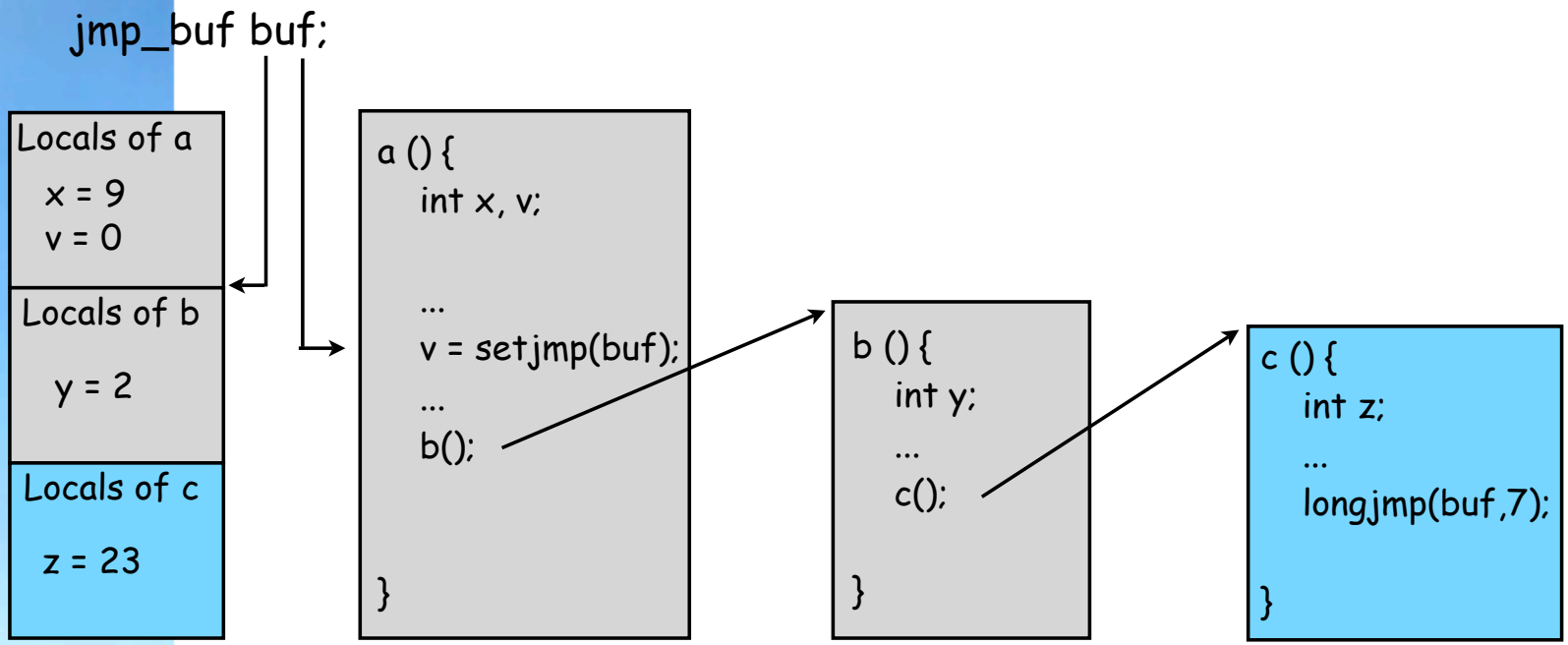

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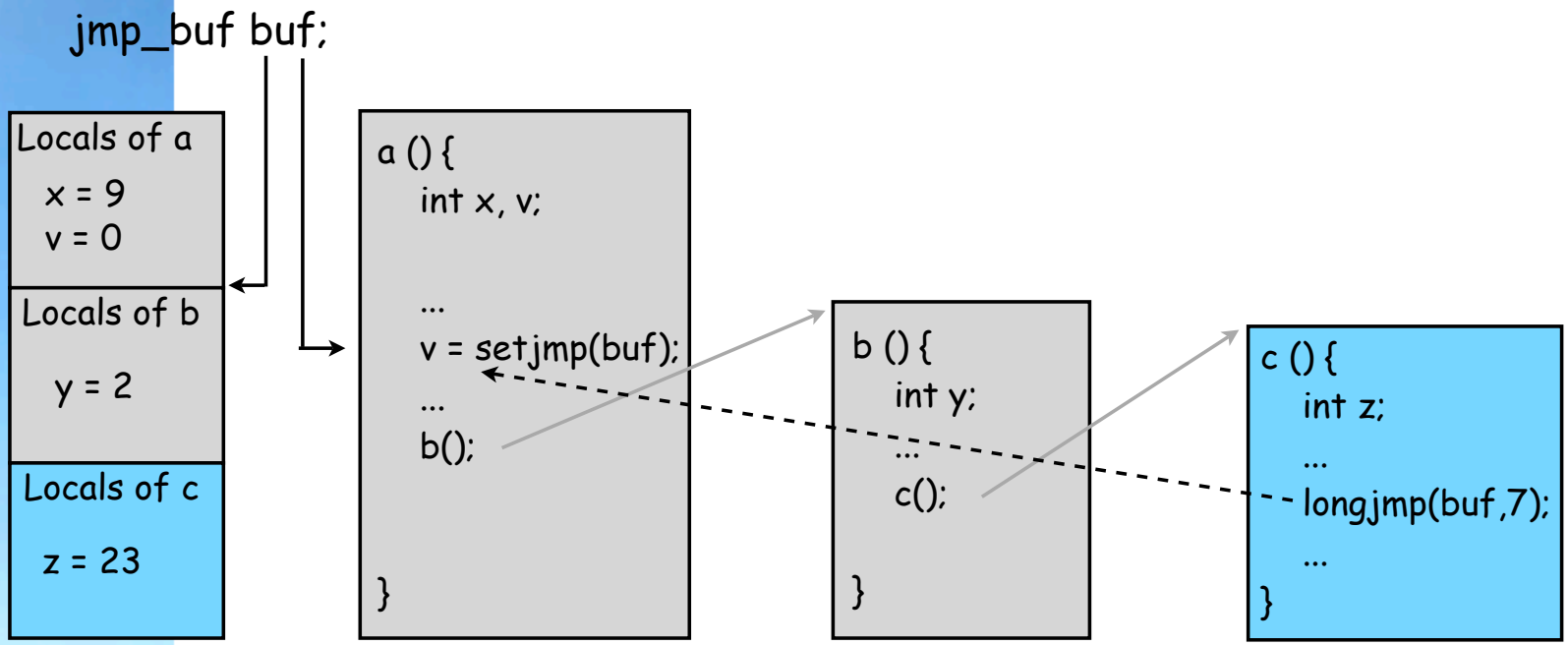

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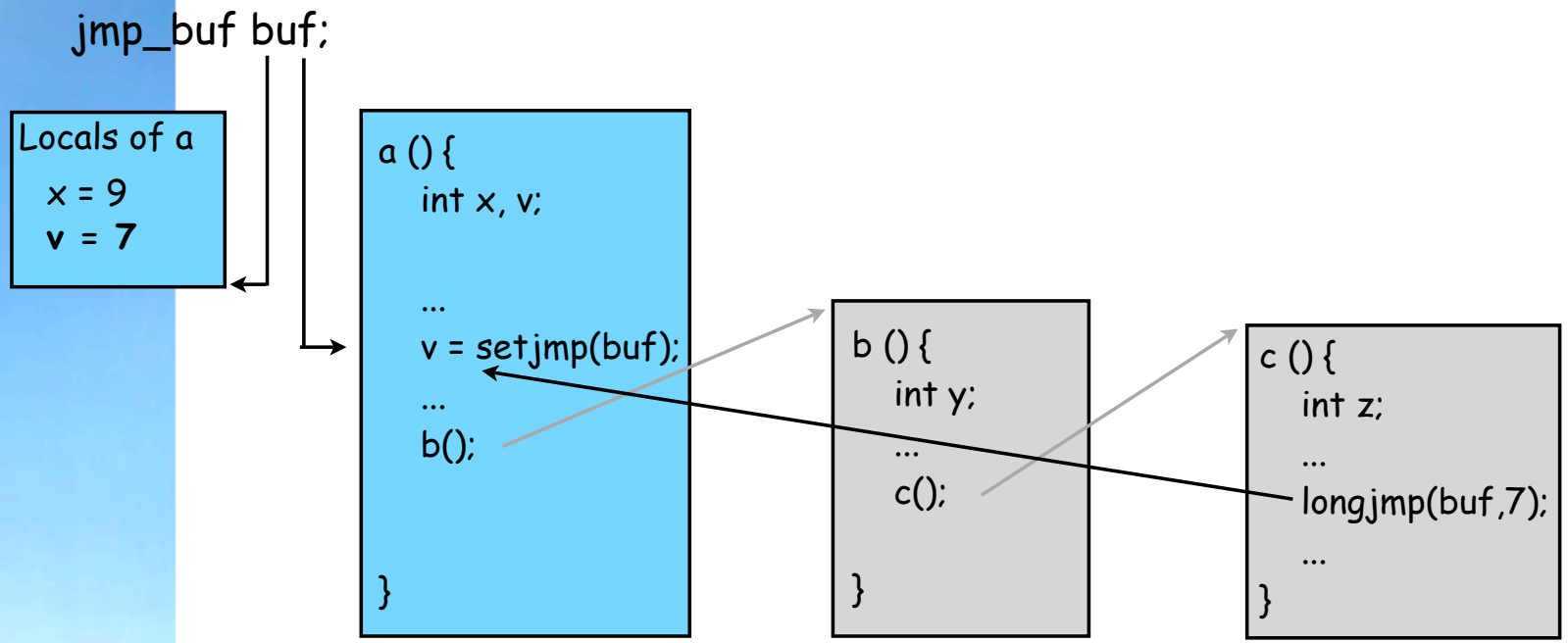

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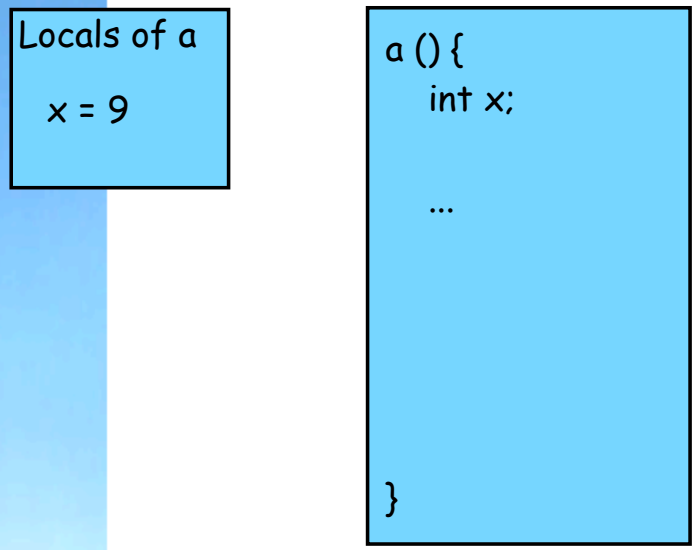

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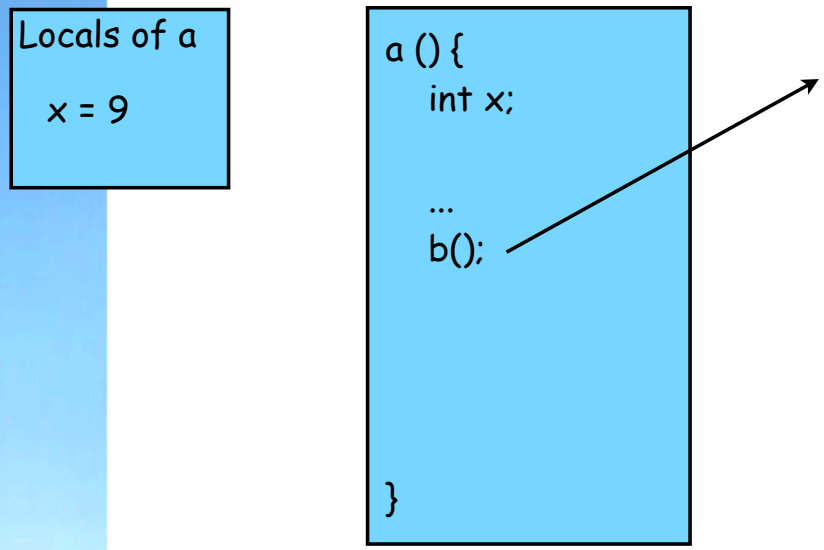

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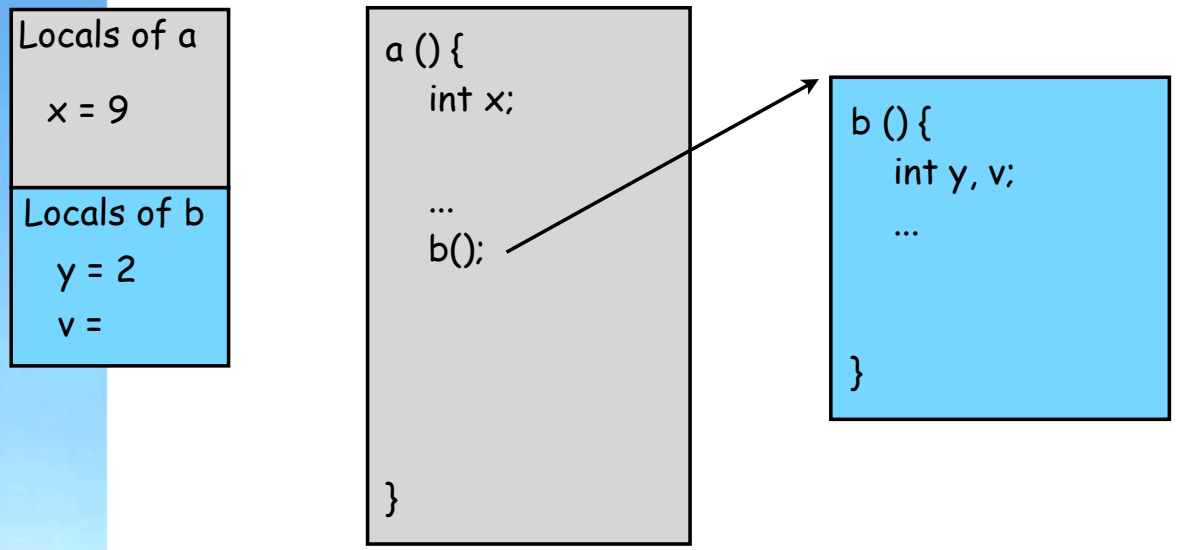

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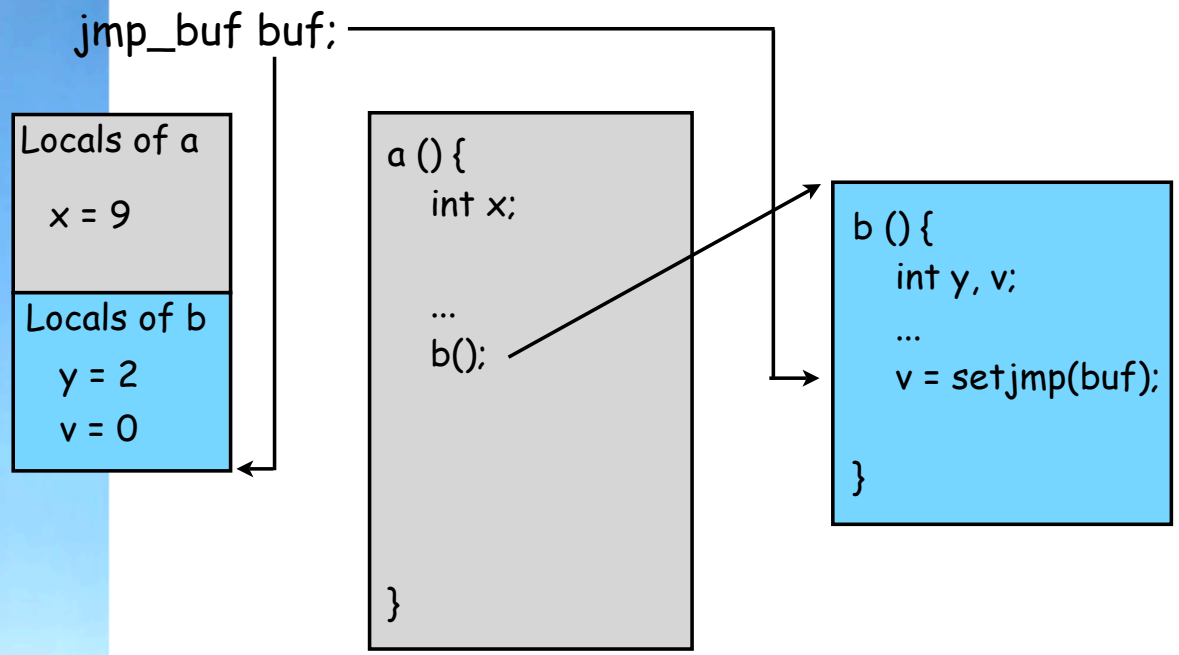

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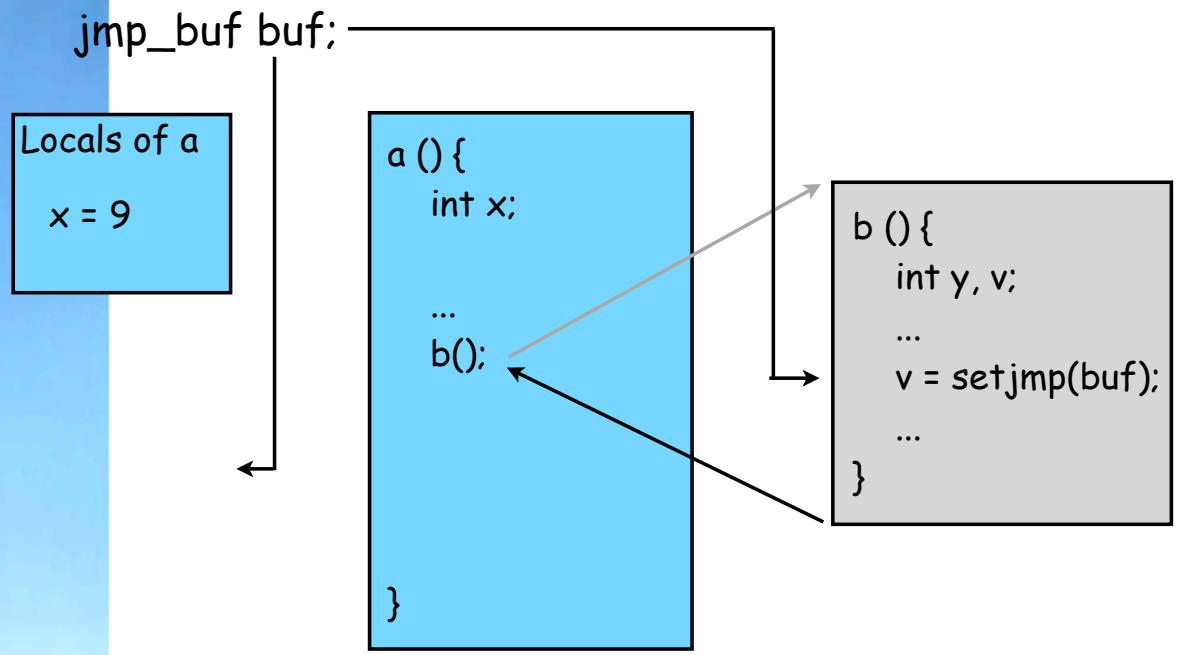

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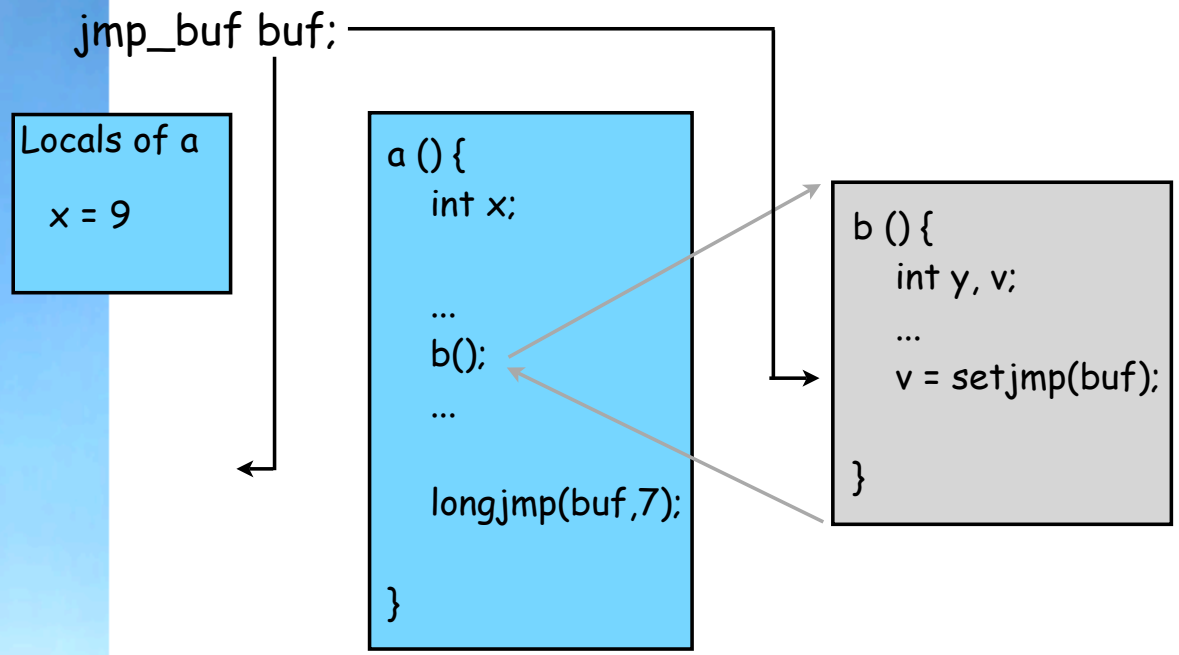

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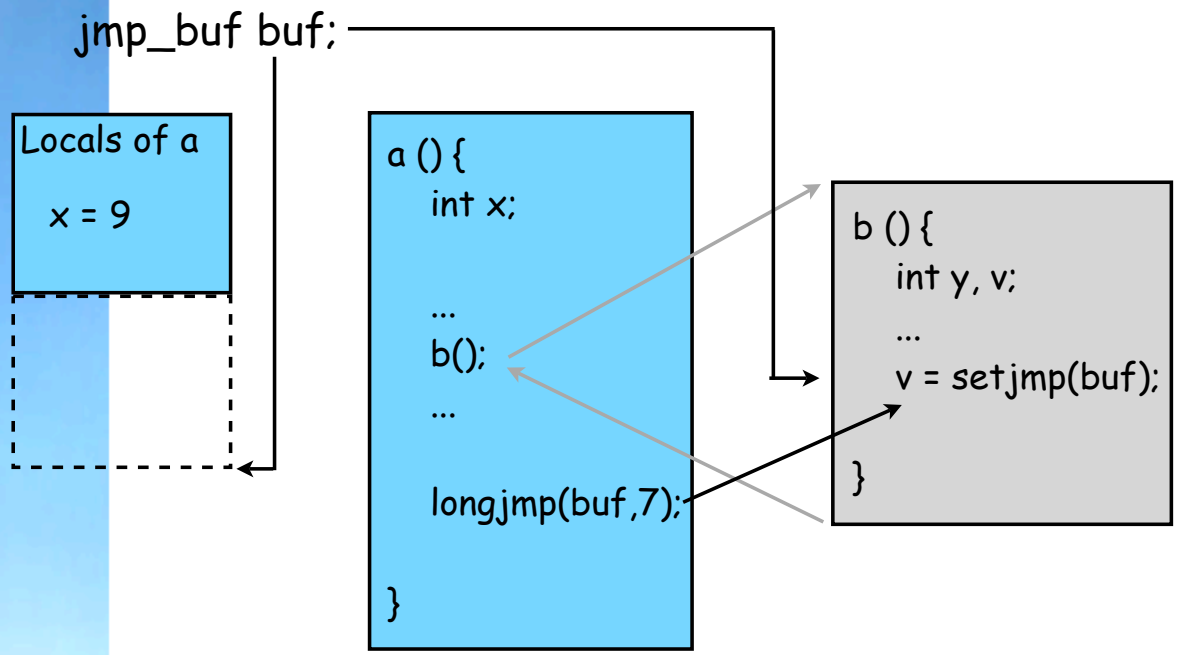

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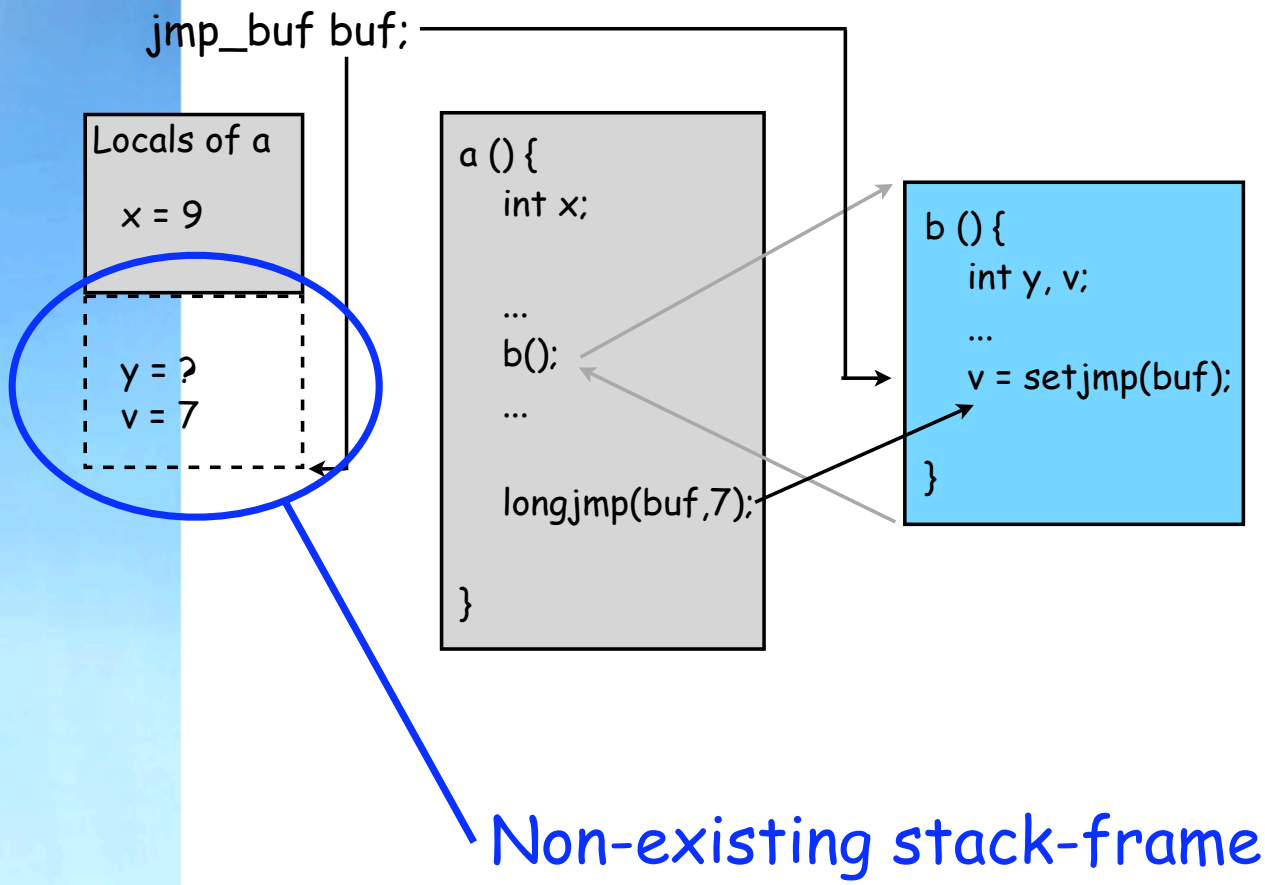

Hacking setjmp/longjmp!

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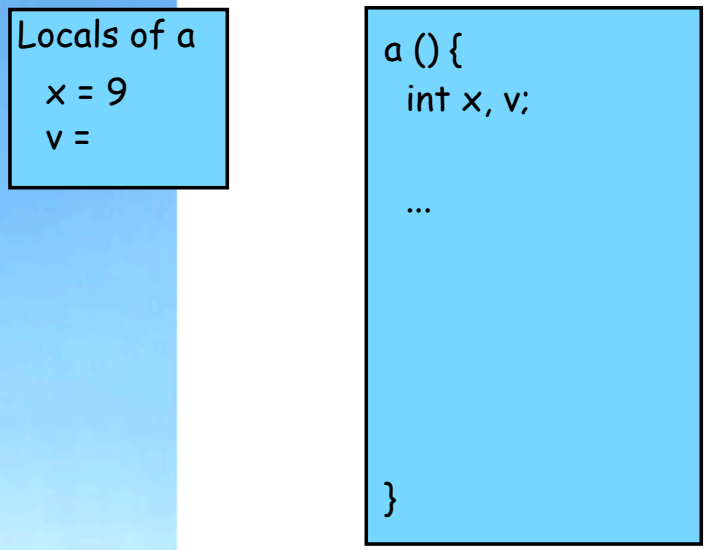

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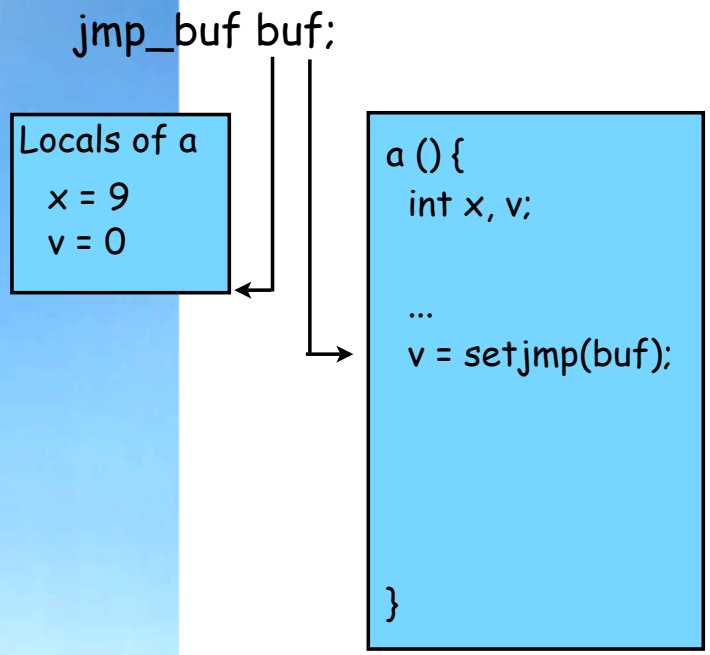

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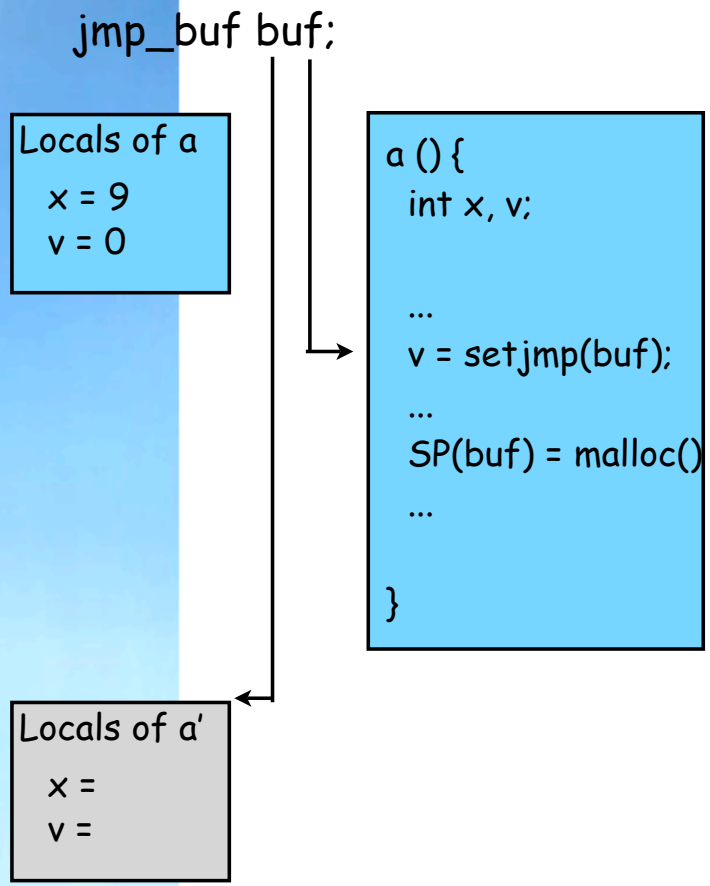

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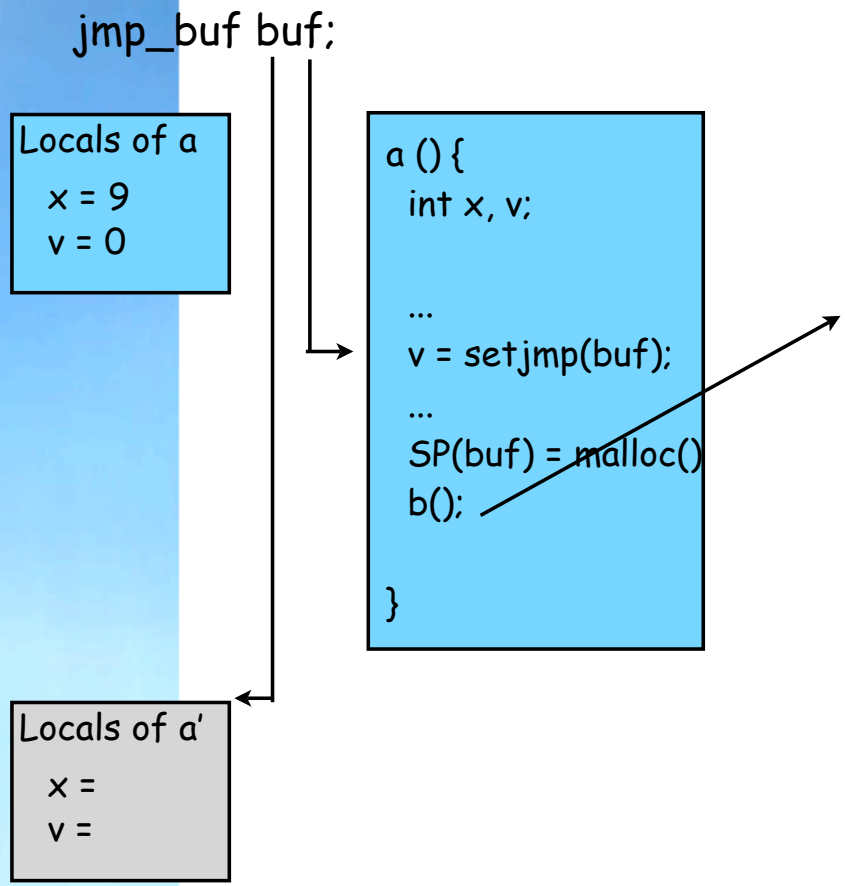

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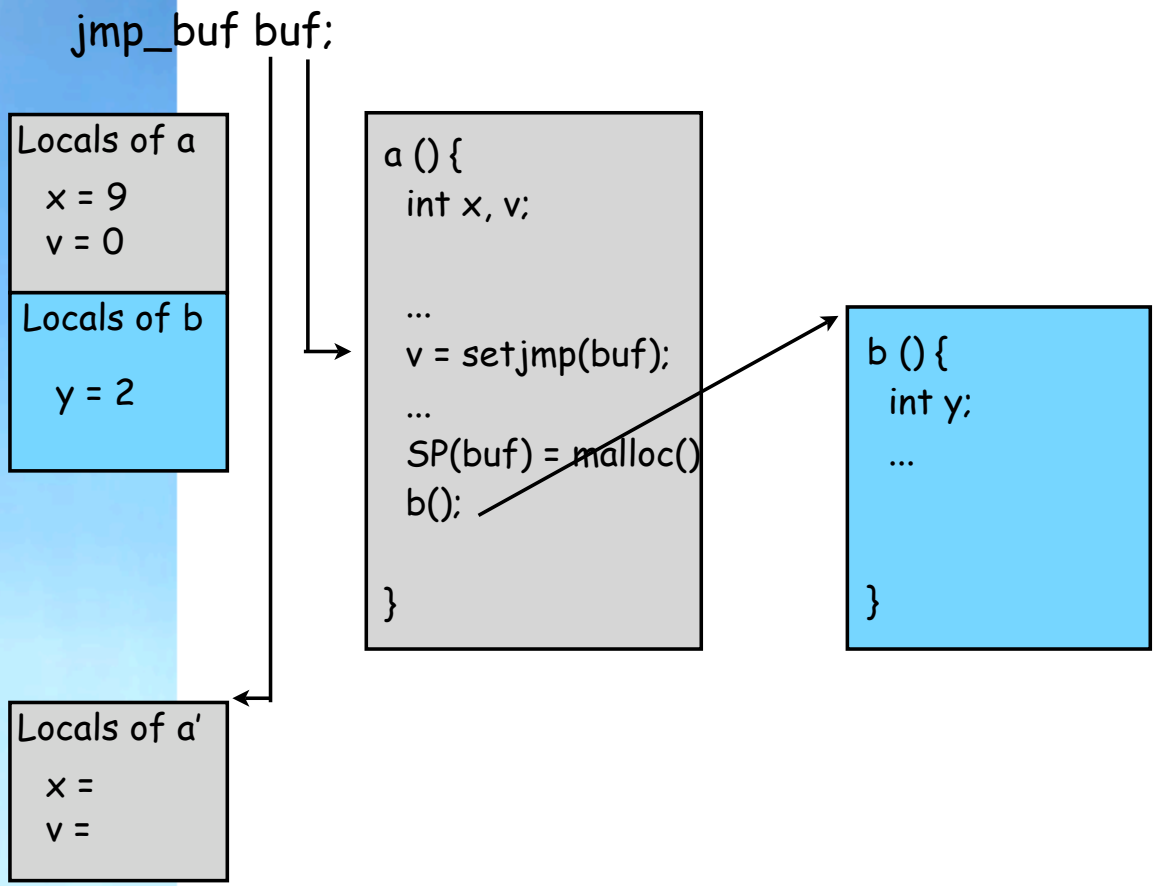

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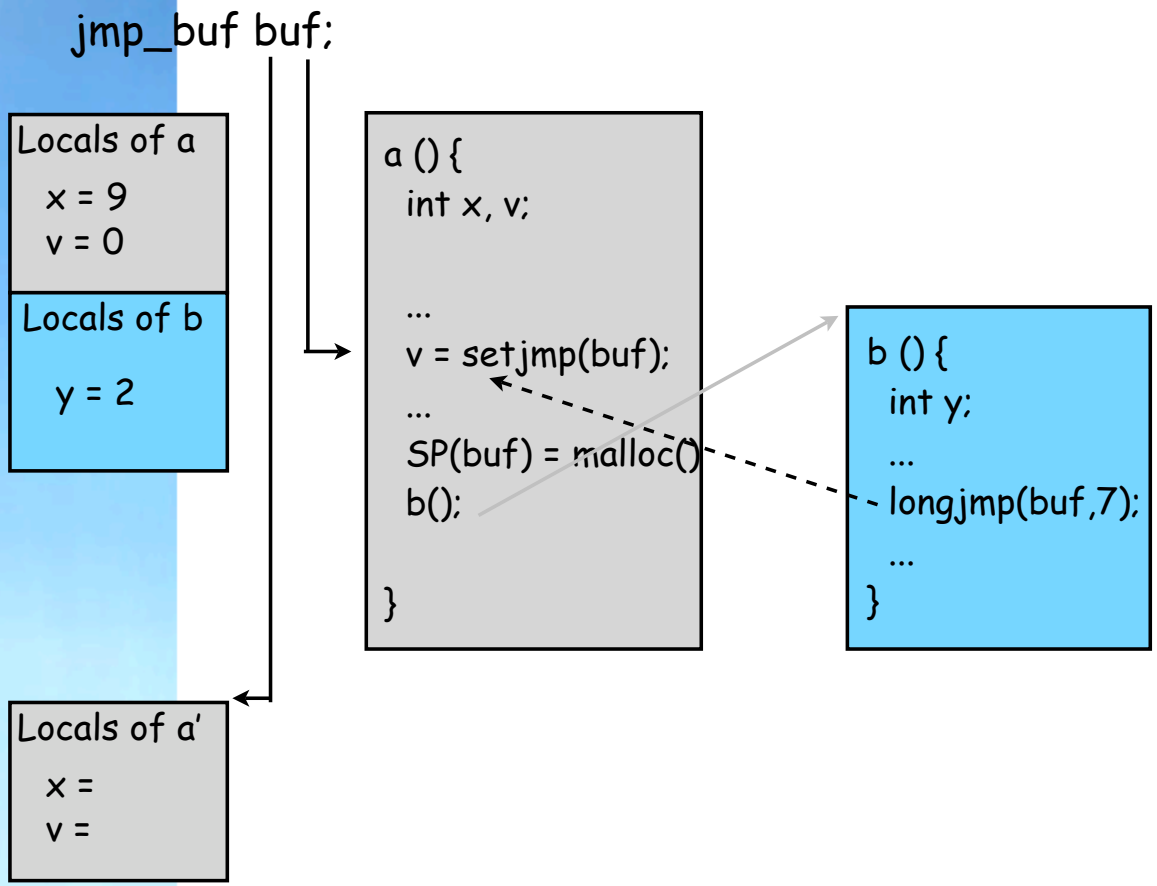

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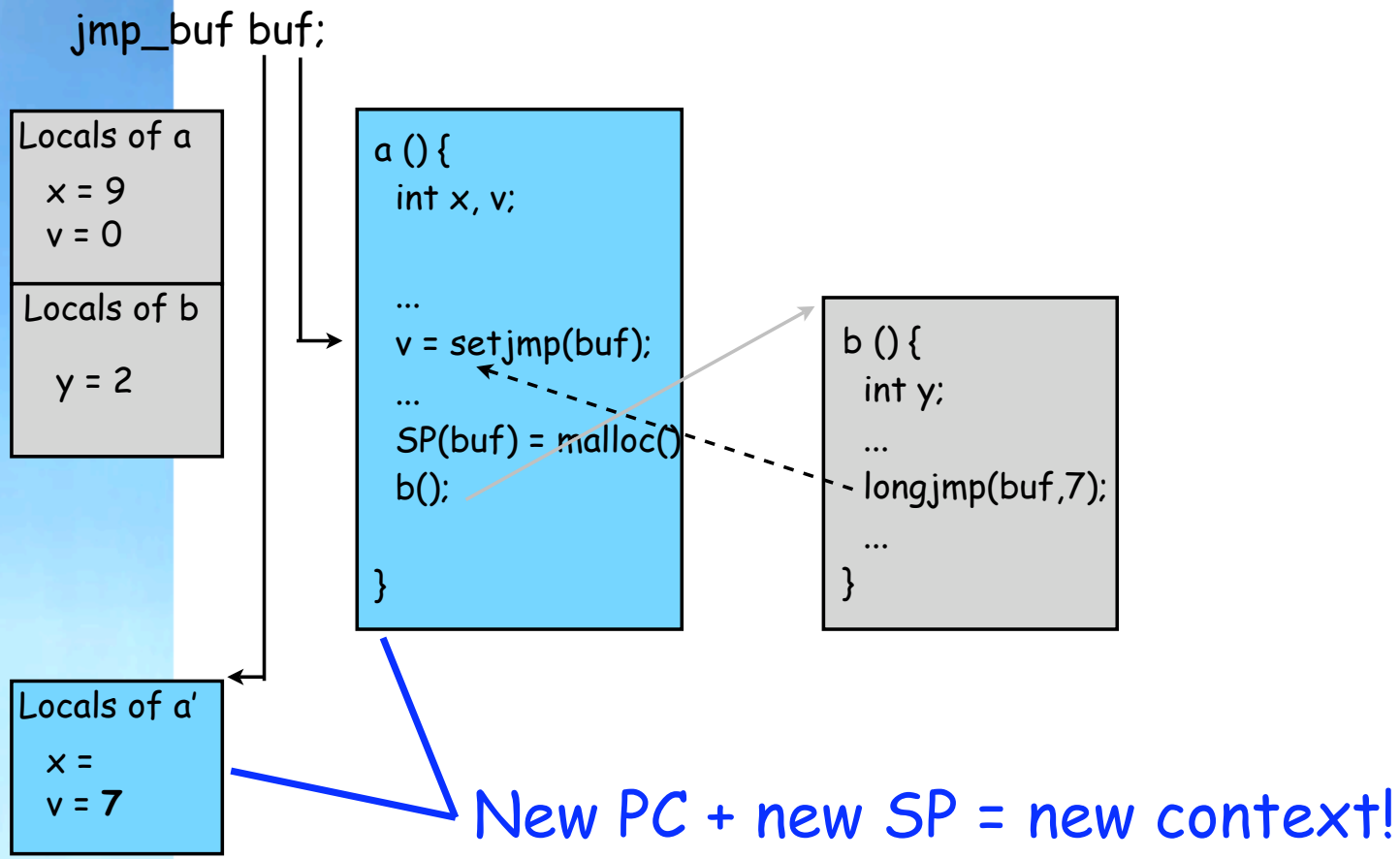


Basic threading idea

- If one has (say) three jmp_bufs A, B, and C, cyclic context-switching can be implemented by running
  setjmp(A); longjmp(B); followed by
  setjmp(B); longjmp(C); followed by
  setjmp(C); longjmp(A);
- However, we can't just let each longjmp chop off a bit of the stack...
- Solution: modify each jmp_buf to point to a unique stack area!
- Warning: the hack required is platform dependent (but it's the only hack we'll need!)

Creating new contexts

Creating a thread context thus means creating a jmp_buf pointing to a fresh stack. Schematically:

```
spawn(void (*fun)(void)) {
    jmp_buf *t = malloc(...);
    if (setjmp(*t) != 0)
        fun();
    STACKPTR(t) = malloc(...);
    // remember t ...
}
```

Caveat: can't really write fun(), because original stack is gone!

Note: macro STACKPTR is highly platform dependent!

The thread block

Associate with each thread a thread block, instead of just a jmp_buf:

```
typedef struct Thread {
    void (*fun)(int);          // code to run
    int arg;                   // argument to the above
    jmp_buf context;           // machine state
    ...                        // more...
} Thread;
```

Let the global variable current point to the running thread block

A second attempt

Now we can write a better spawn:

```
spawn(void (*fun)(int), int arg) {
    Thread *t = malloc(...);
    t->fun = fun;
    t->arg = arg;
    if (setjmp(t->context) != 0)
        current->fun(current->arg);
    STACKPTR(t) = malloc(...);
    // remember t ...
}
```

Q 1: who sets current?

Q 2: what happens when fun returns?

The ready queue

- If all runnable threads are kept in a queue, we can implement a function yield() that switches execution to another thread
- yield() must
  - enqueue the current thread at the ready queue
  - pick a new thread from the ready queue
  - update current
  - perform the setjmp(A); longjmp(B) trick to switch contexts – a dispatch
- Later on we can try to make yield() happen automatically; i.e., by means of an interrupt!

The dispatch function

Assuming that current points to the running thread block, a dispatch can be implemented as follows:

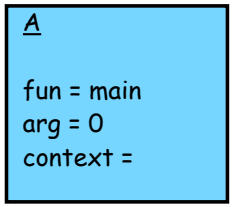
```
void dispatch(Thread *next) {
    if (setjmp(current->context) == 0) {
        current = next;
        longjmp(next->context,1);
    }
}
```

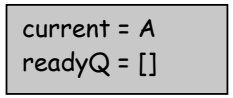
Note that the function returns directly when control later enters via the "fake return" from setjmp

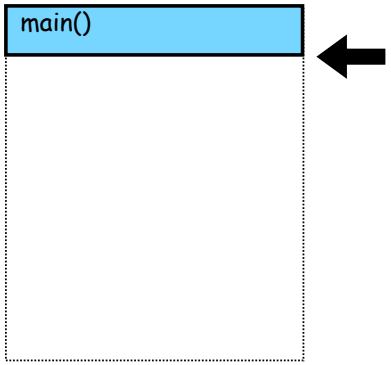
Putting it all together

- We will run through a complete stepwise execution of a program that spawns a thread that computes prime numbers, and then goes on to compute prime numbers itself too
- The current code and stack pointers of the cpu are denoted by thick arrows
- Other pointers, as well as the ready queue, will be represented informally
- The code will be schematic, but full details can be found in lab assignment 2
- Global variables are in the middle, stacks to the right

```
void yield() {
    enqueue(current, &readyQ);
    dispatch(dequeue(&readyQ));
}

void dispatch(Thread *next) {
    if (setjmp(current->context) == 0) {
        current = next;
        longjmp(next->context, 1);
    }
}

void spawn(void (*fun)(int), int arg) {
    Thread *t = malloc(...)
    t->fun = fun;
    t->arg = arg;
    if (setjmp(t->context) == 1) {
        current->fun(current->arg);
        dispatch(dequeue(&readyQ));
    }
    STACKPTR(t->context) = malloc(...)
    enqueue(t, &readyQ);
    ...
}

primes(int start) {
    int n = start;
    while (...) {
        ...
        if (...) yield();
    }
}

main() {
    spawn(primes, 101);
    primes(202);
}
```







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        longjmp(next->context, 1);
    }
}

void spawn(void (*fun)(int), int arg) {
    Thread *t = malloc(...)
    t->fun = fun;
    t->arg = arg;
    if (setjmp(t->context) == 1) {
        current->fun(current->arg);
        dispatch(dequeue(&readyQ));
    }
    STACKPTR(t->context) = malloc(...)
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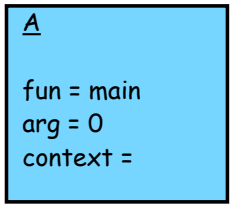

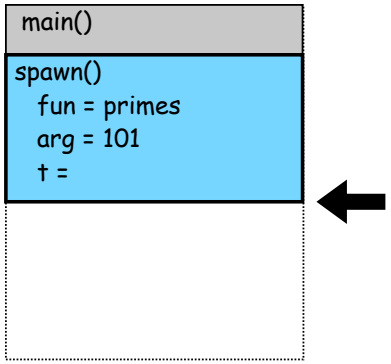

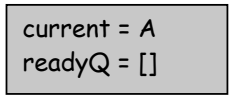

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    }
}

void spawn(void (*fun)(int), int arg) {
    Thread *t = malloc(...)
    t->fun = fun;
    t->arg = arg;
    if (setjmp(t->context) == 1) {
        current->fun(current->arg);
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    }
    STACKPTR(t->context) = malloc(...)
    enqueue(t, &readyQ);
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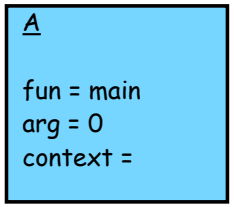

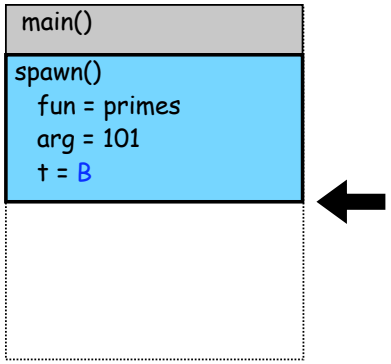

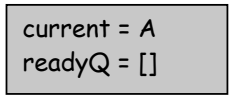

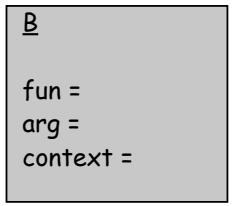

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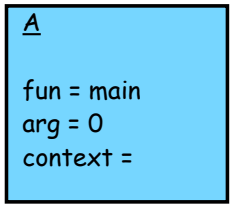

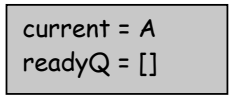

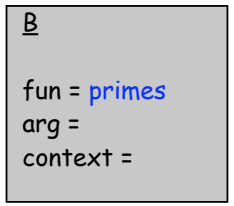

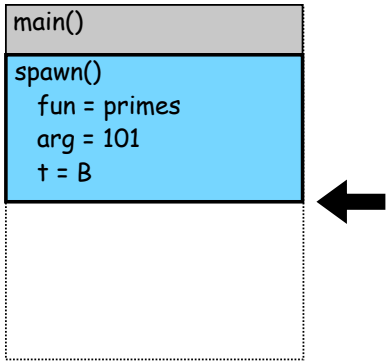

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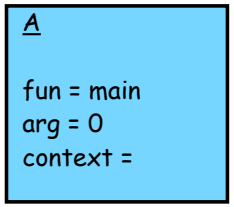

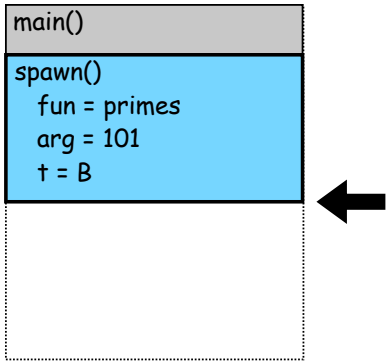

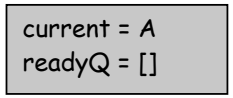

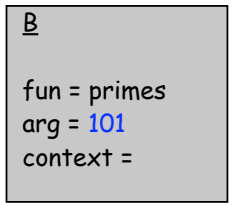

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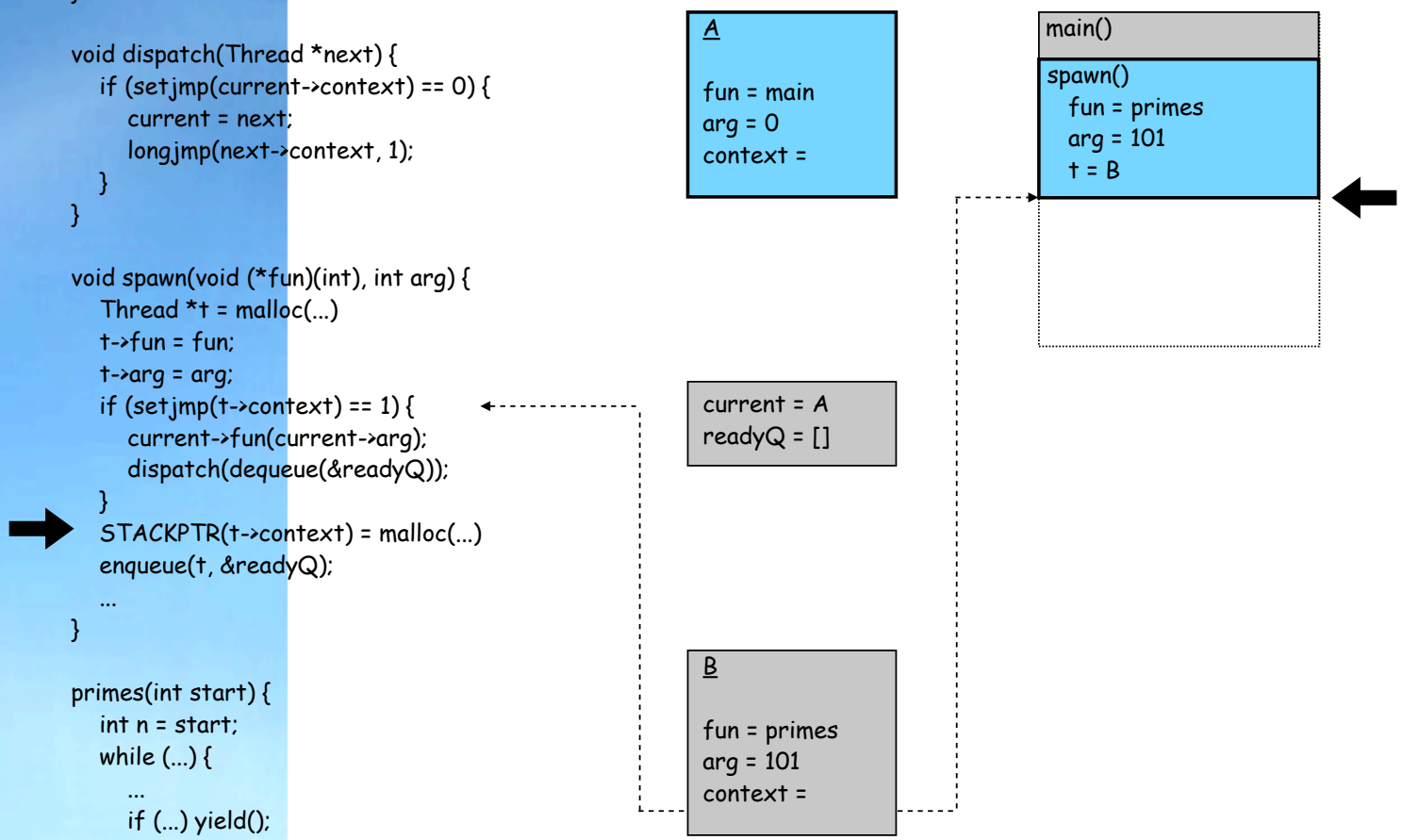

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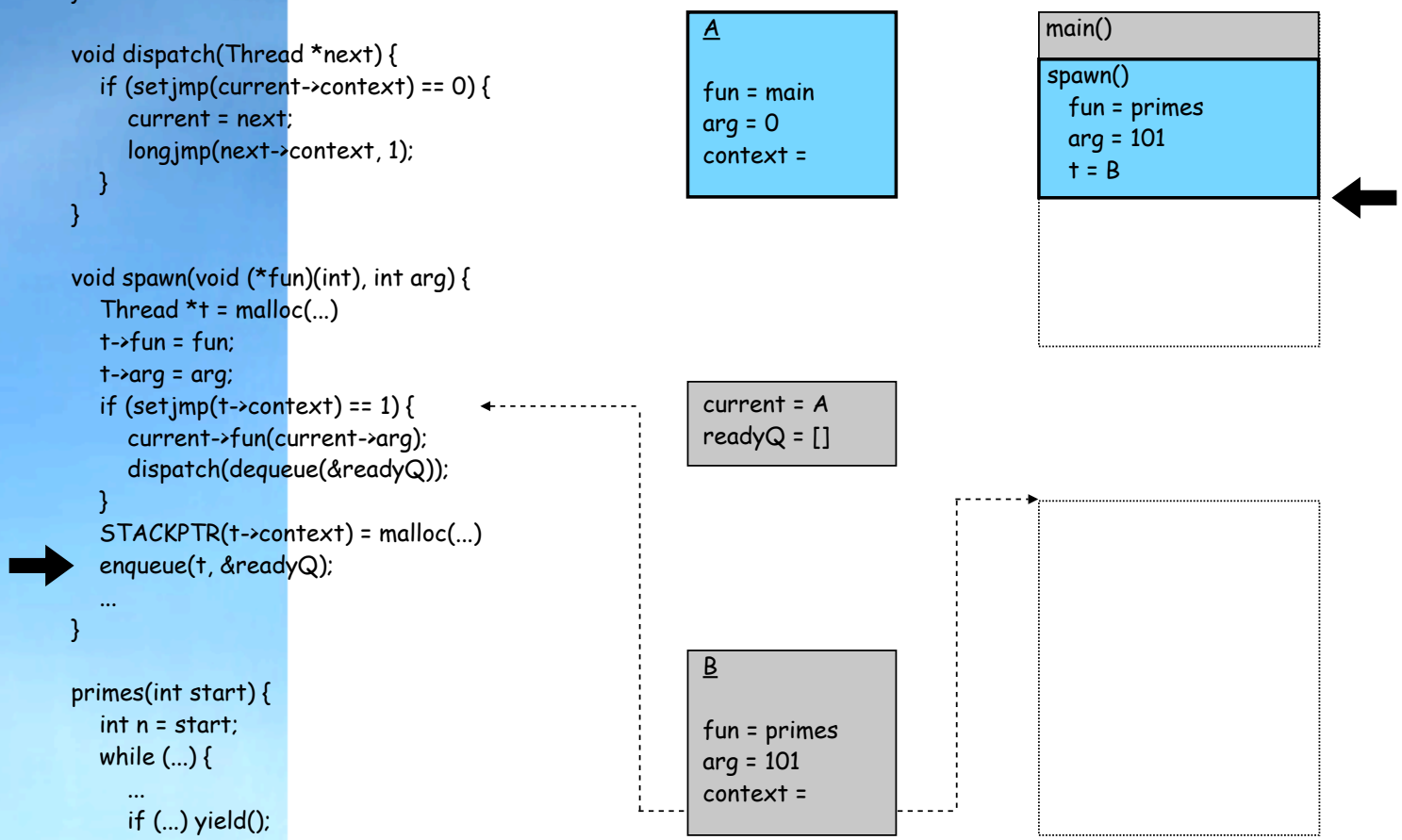

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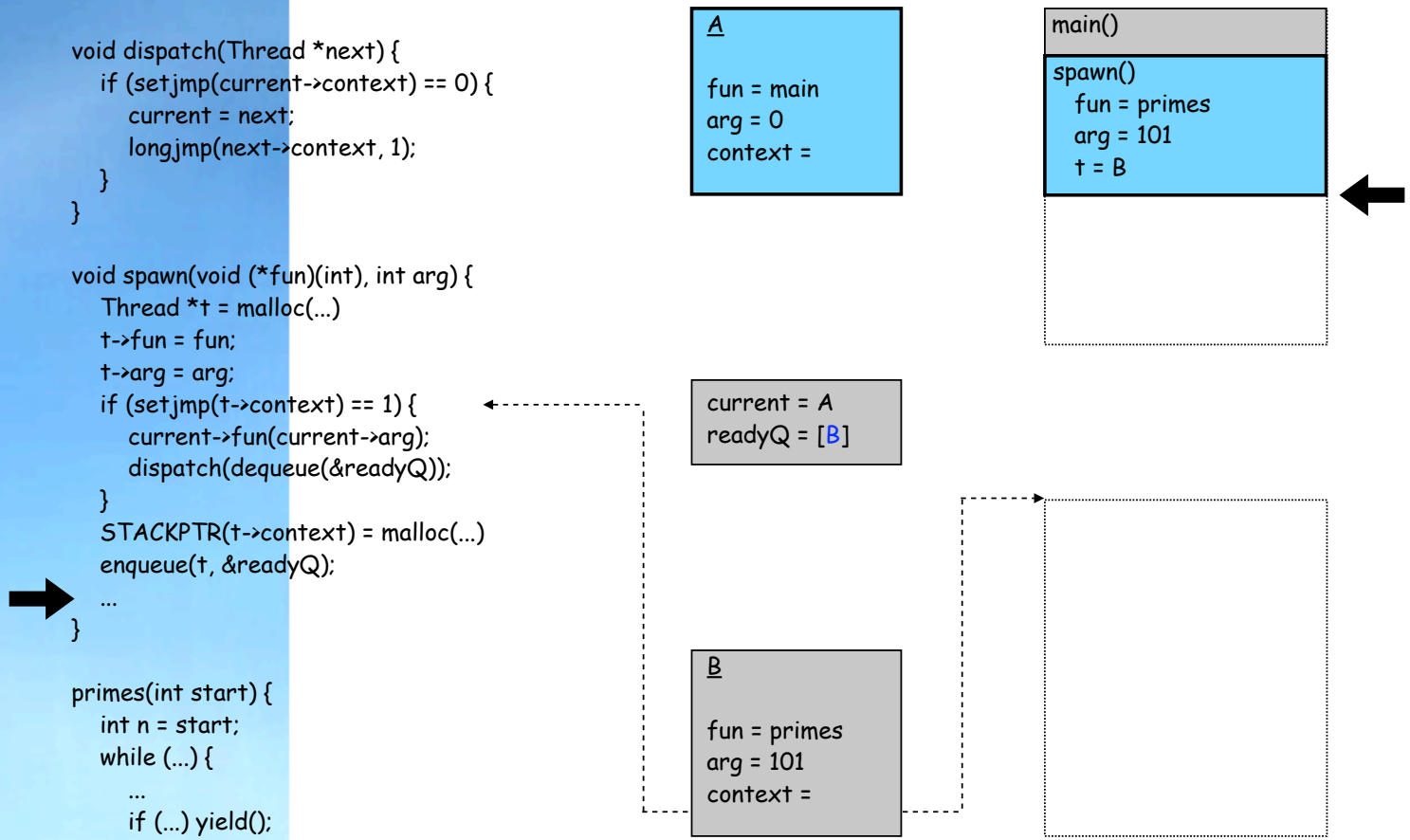

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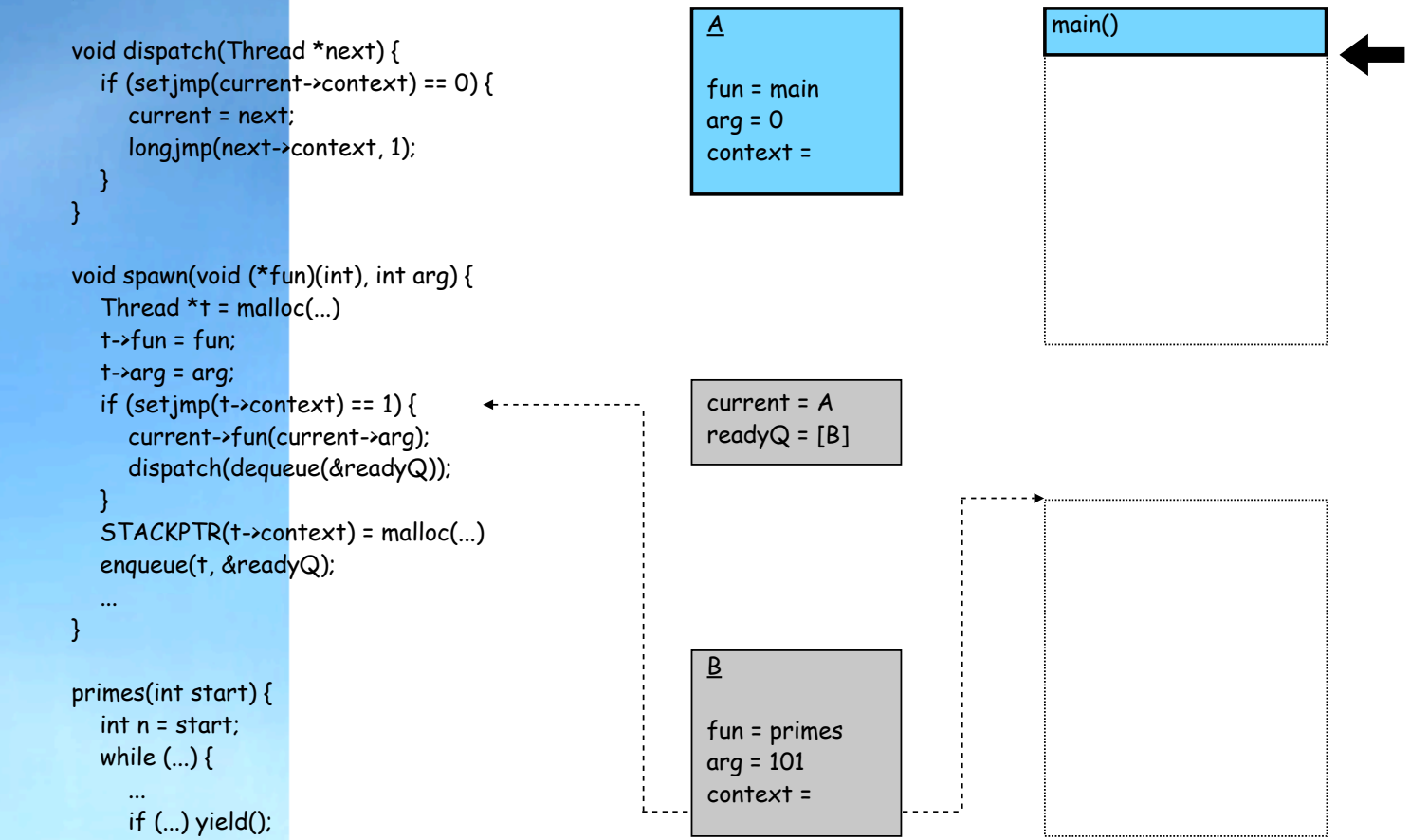

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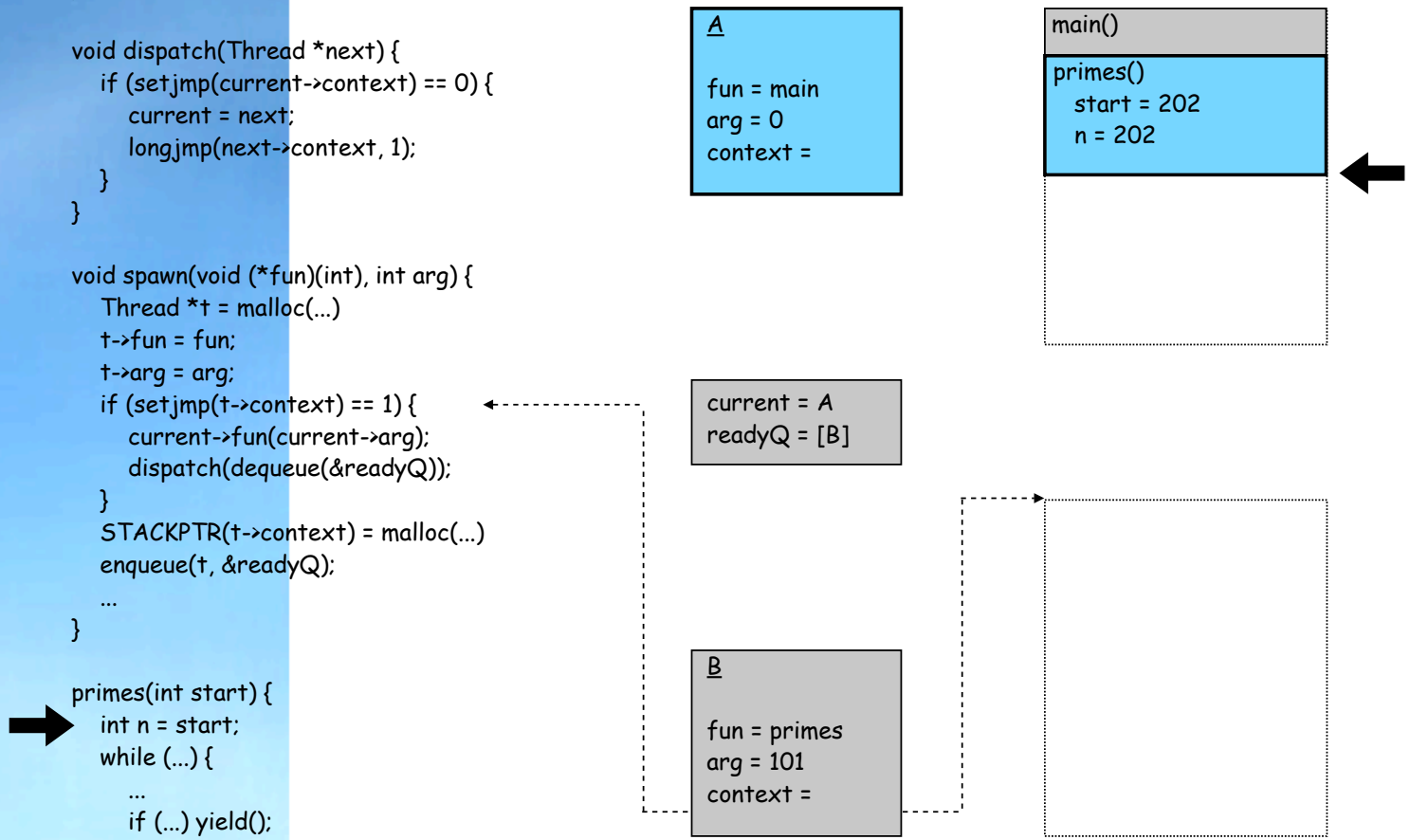

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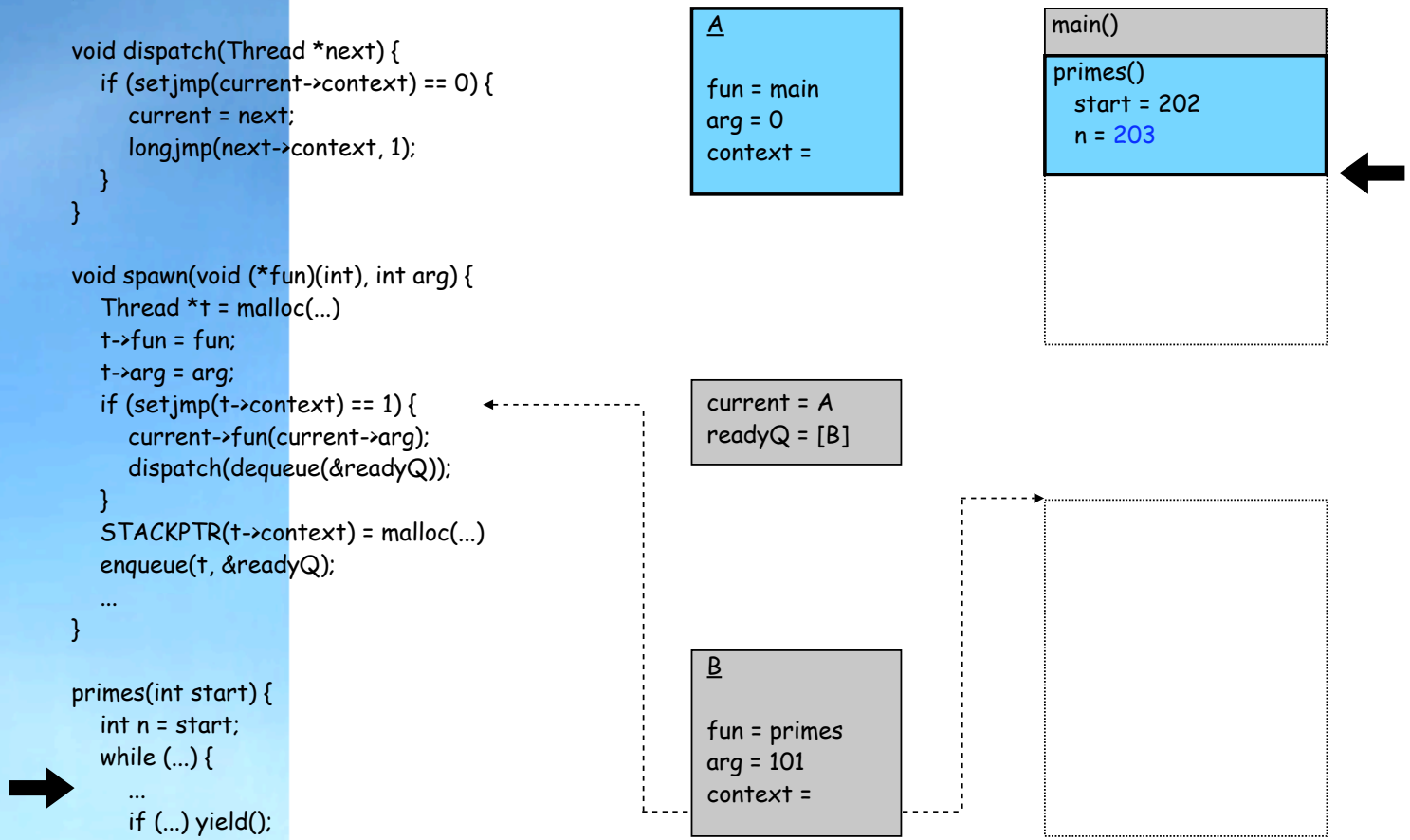

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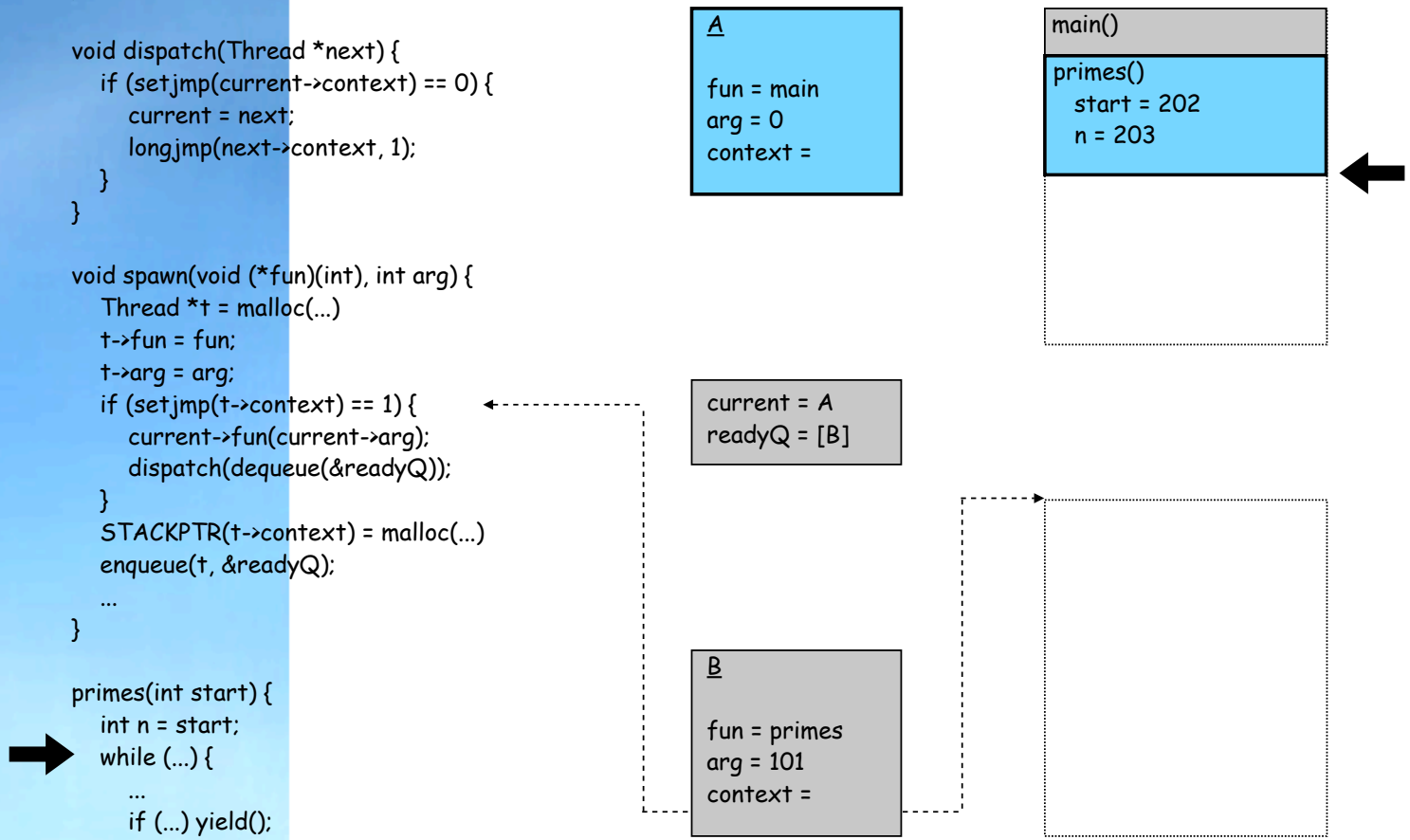

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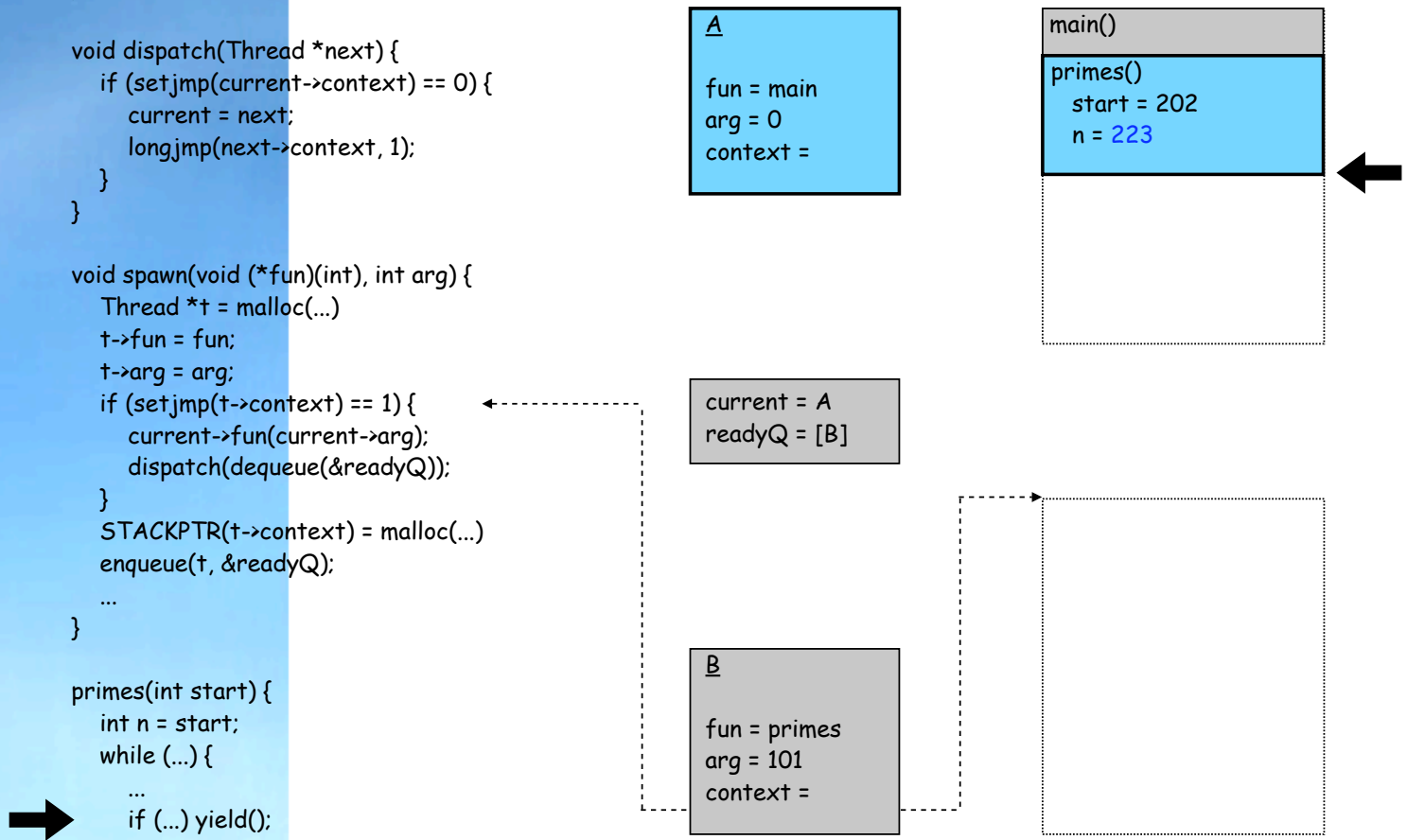

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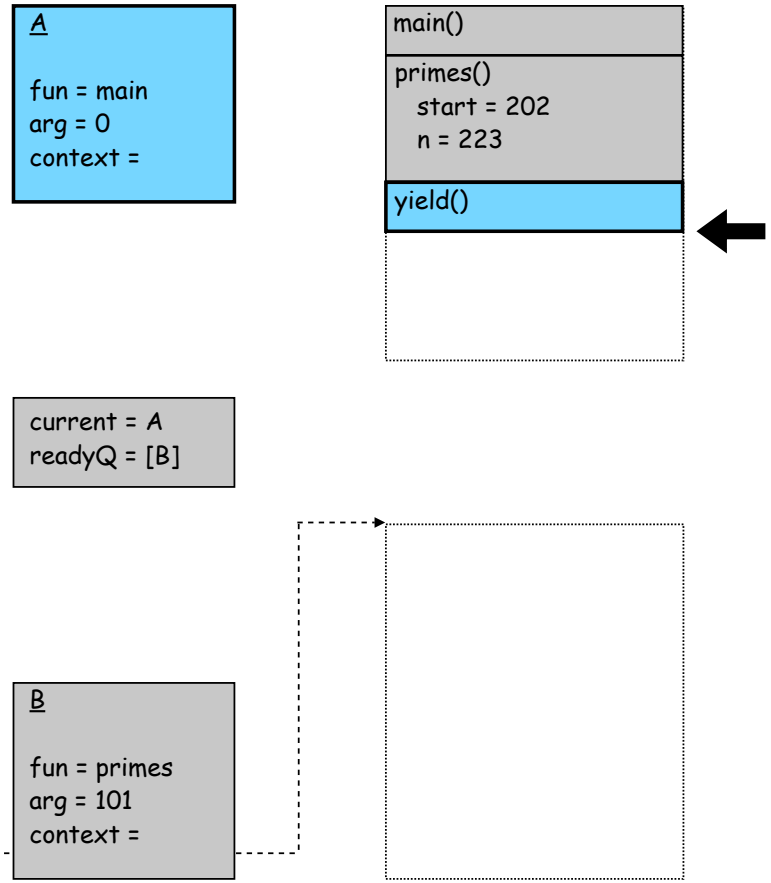

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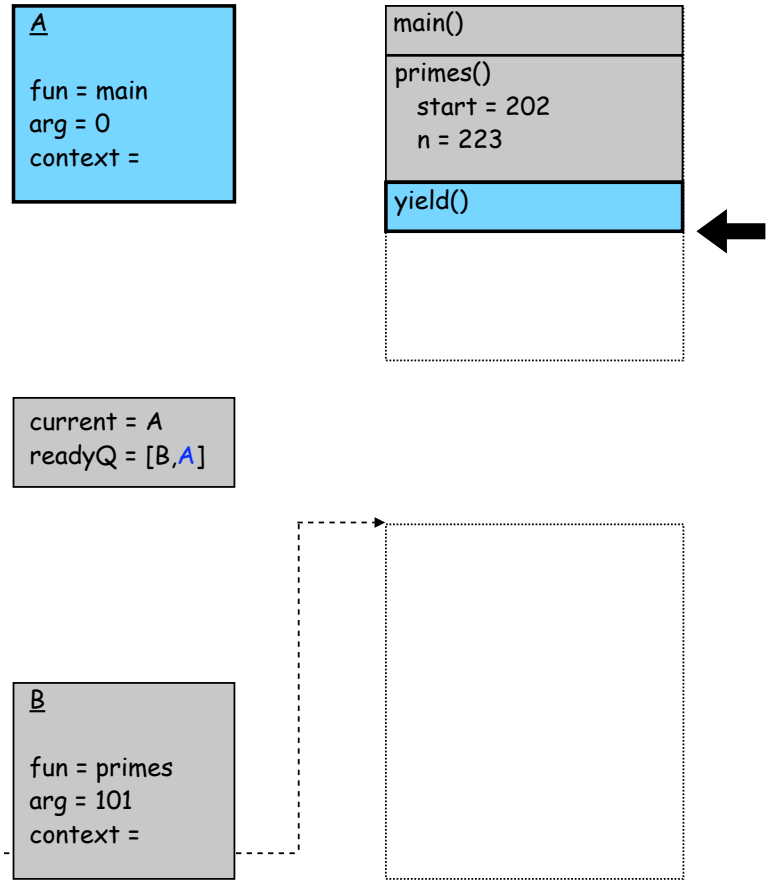

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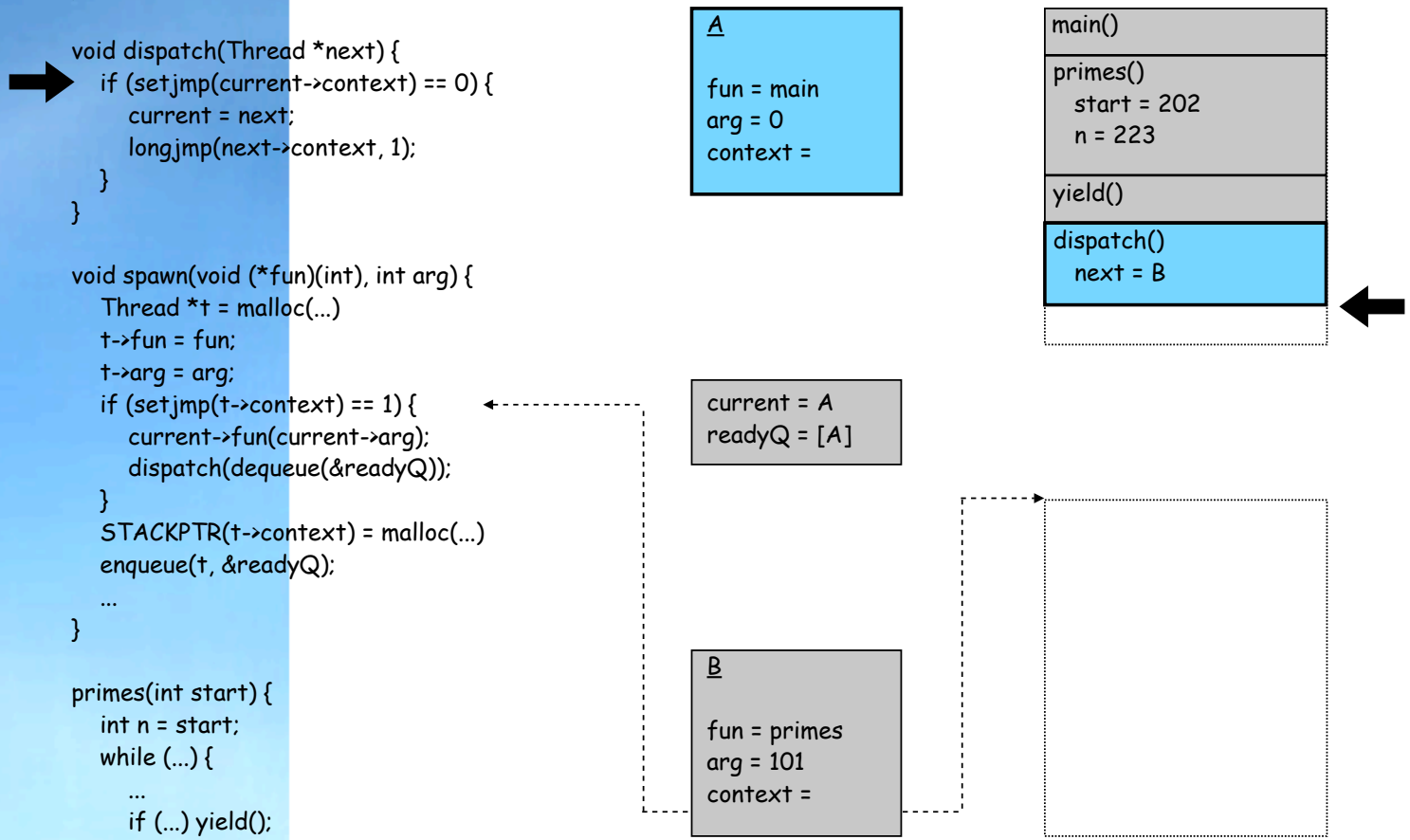

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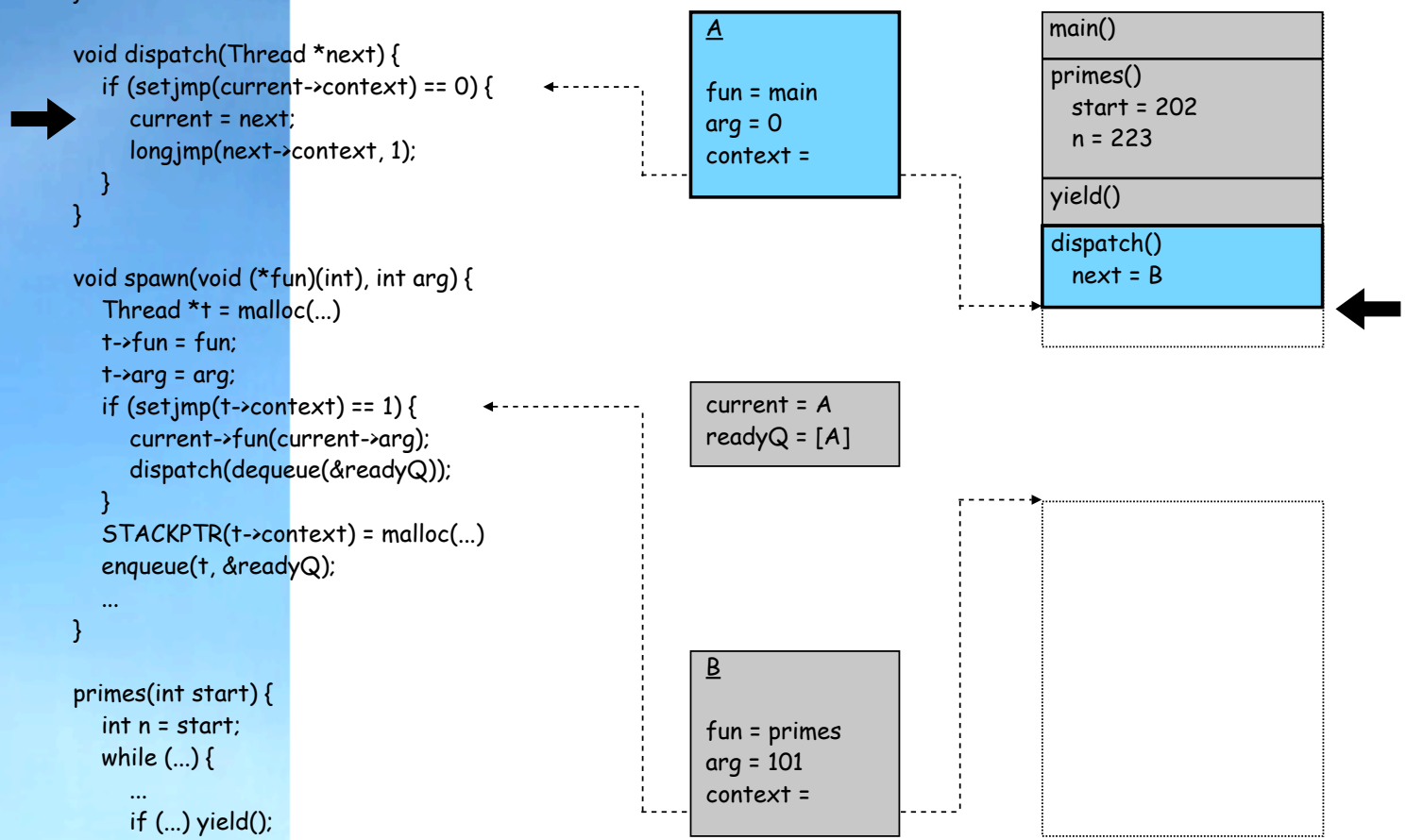

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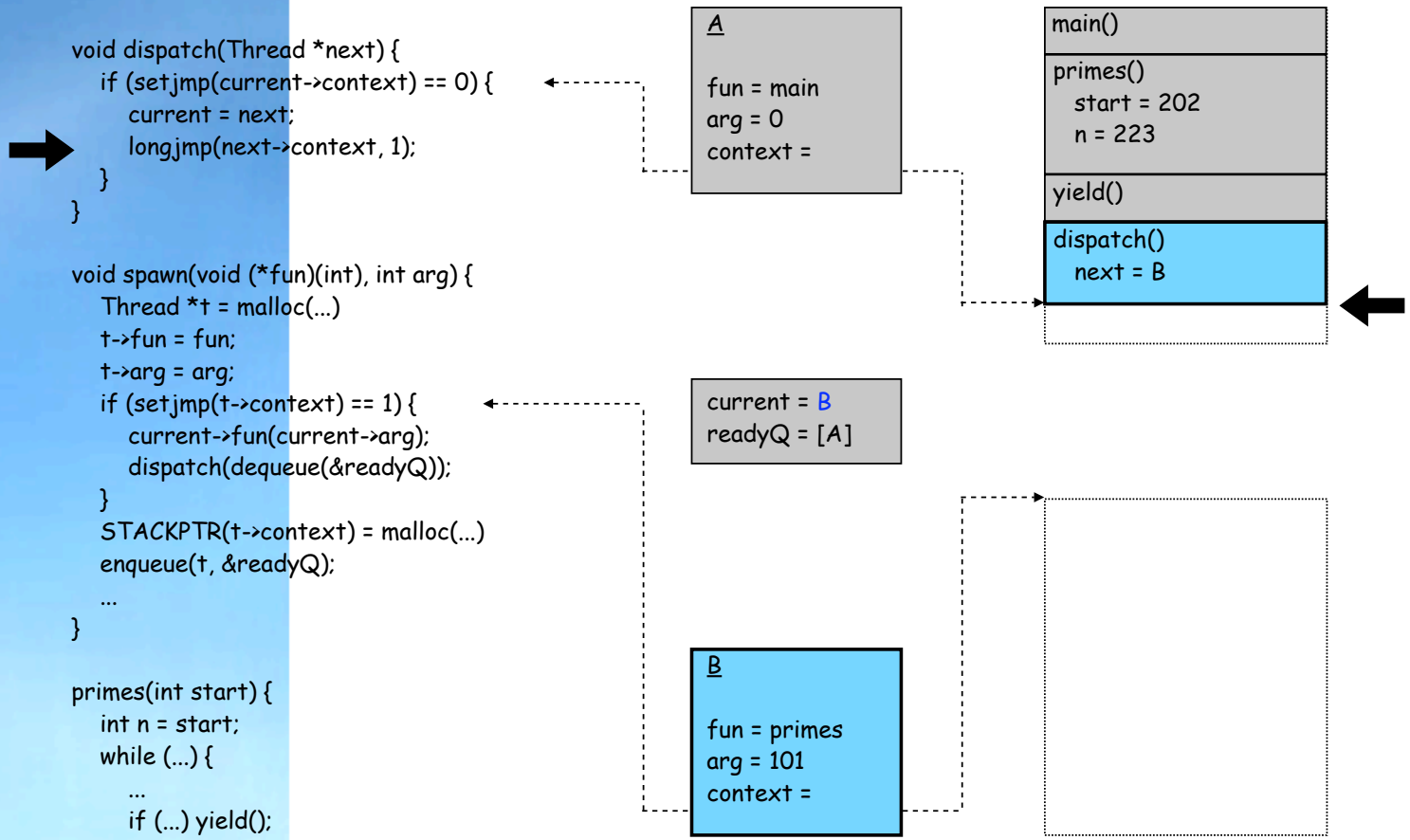

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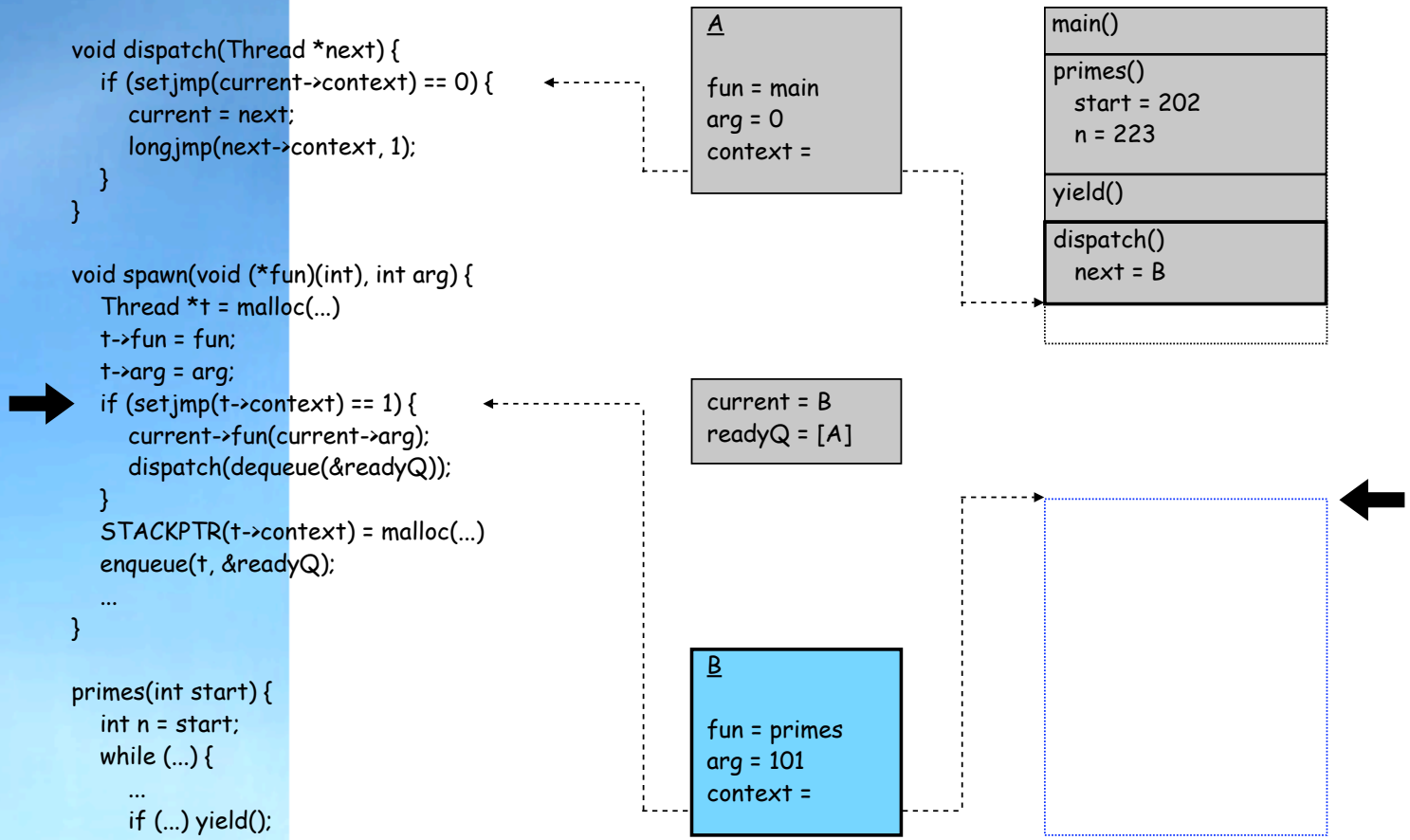

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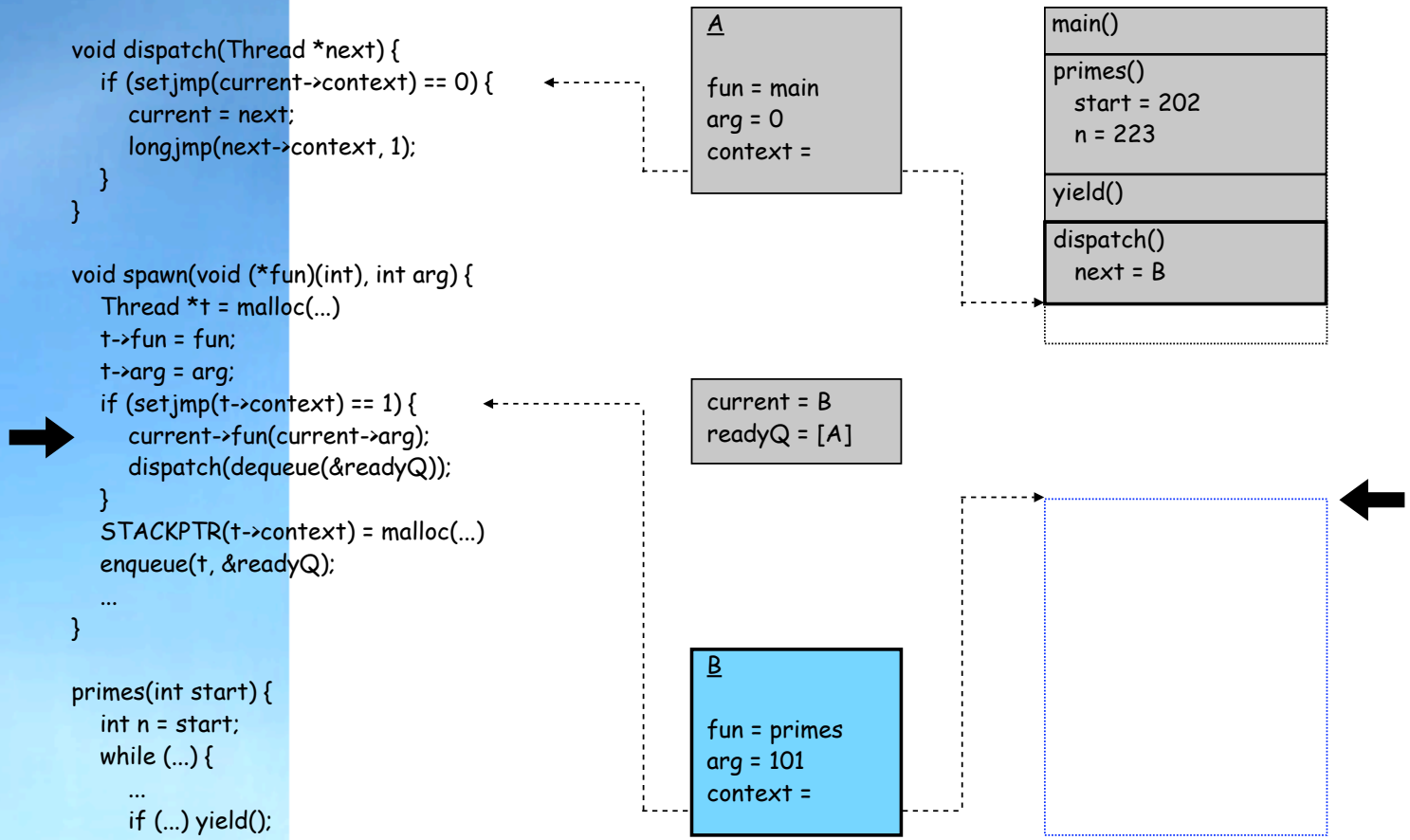

Note that fun and arg can't be found on the stack anymore!

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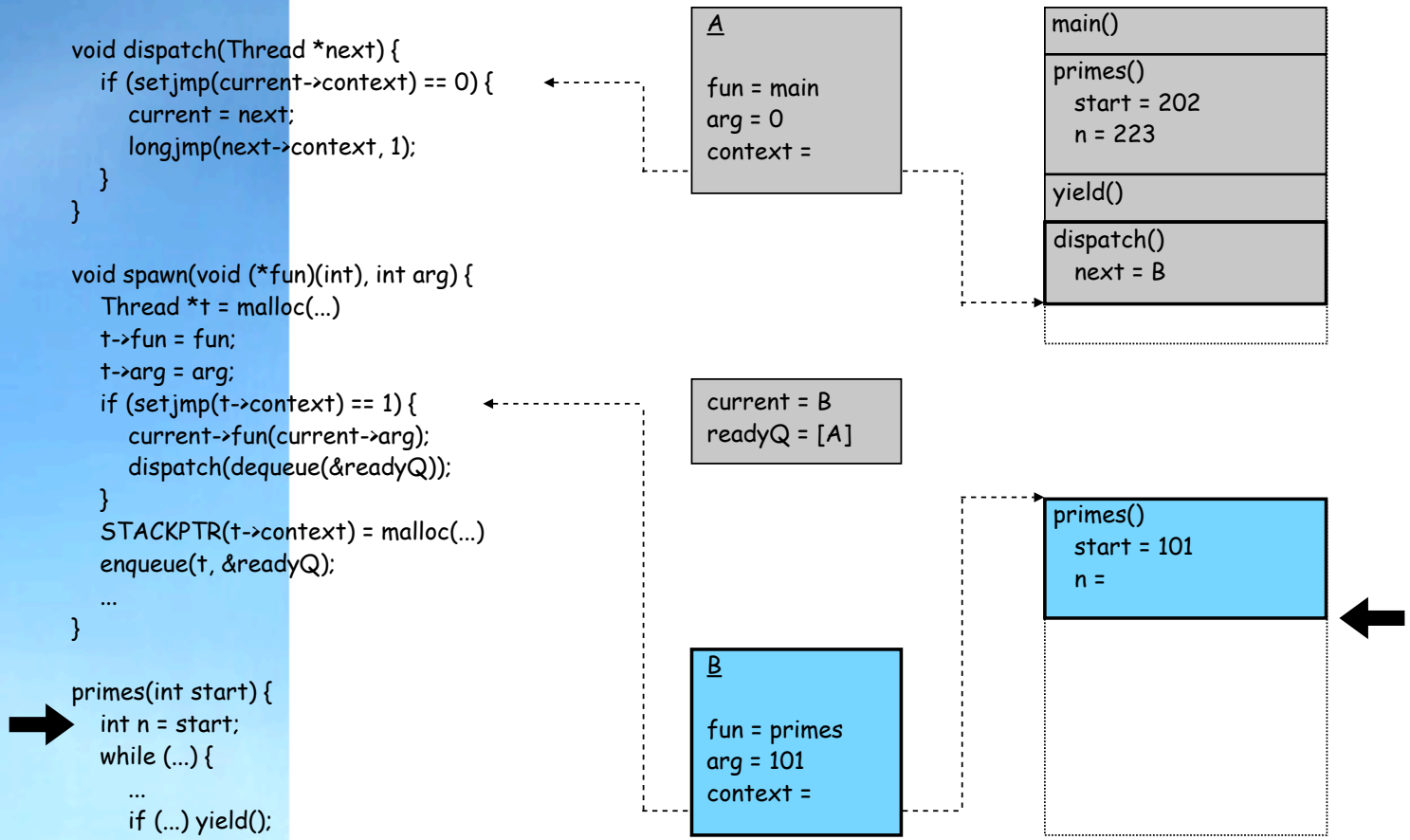

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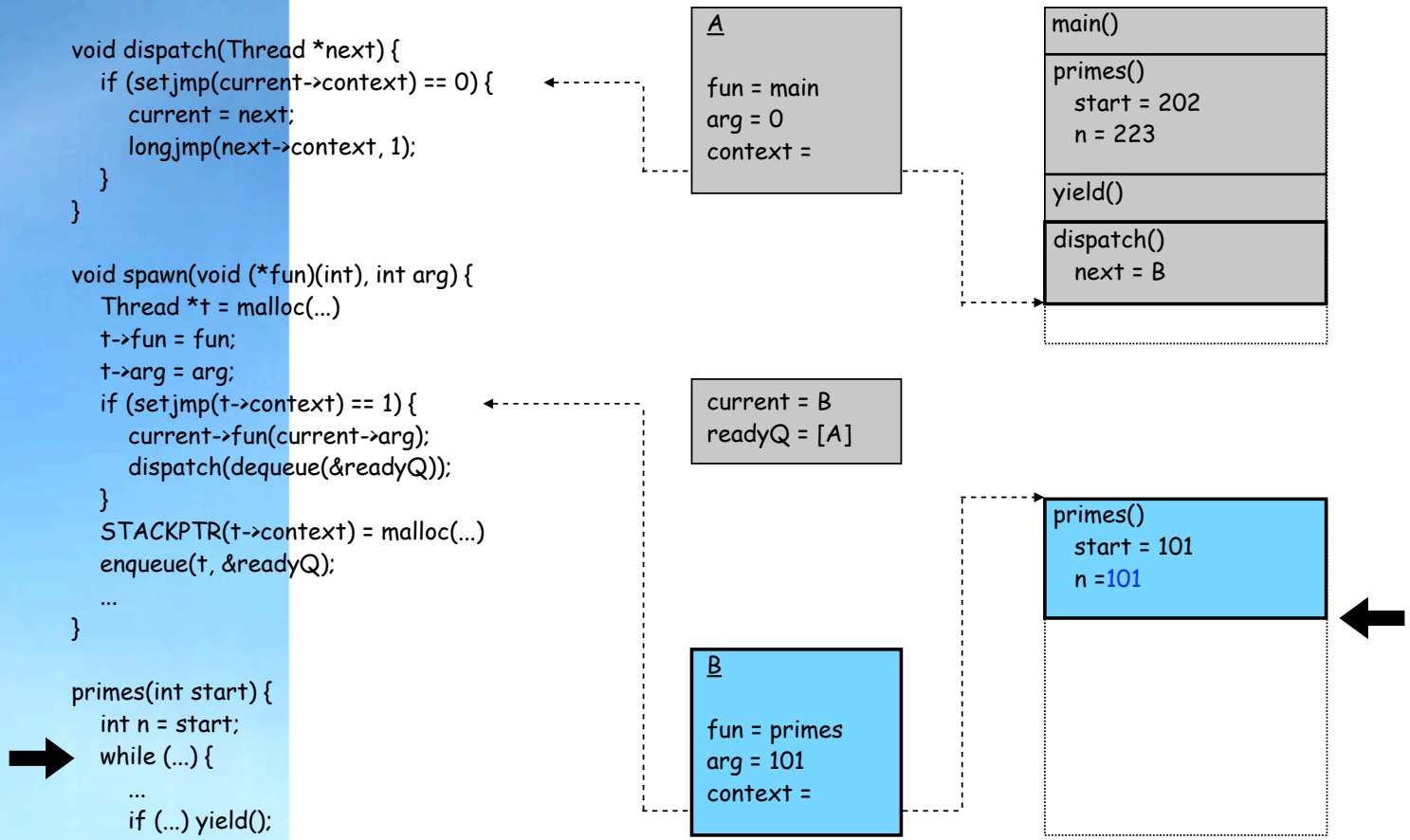

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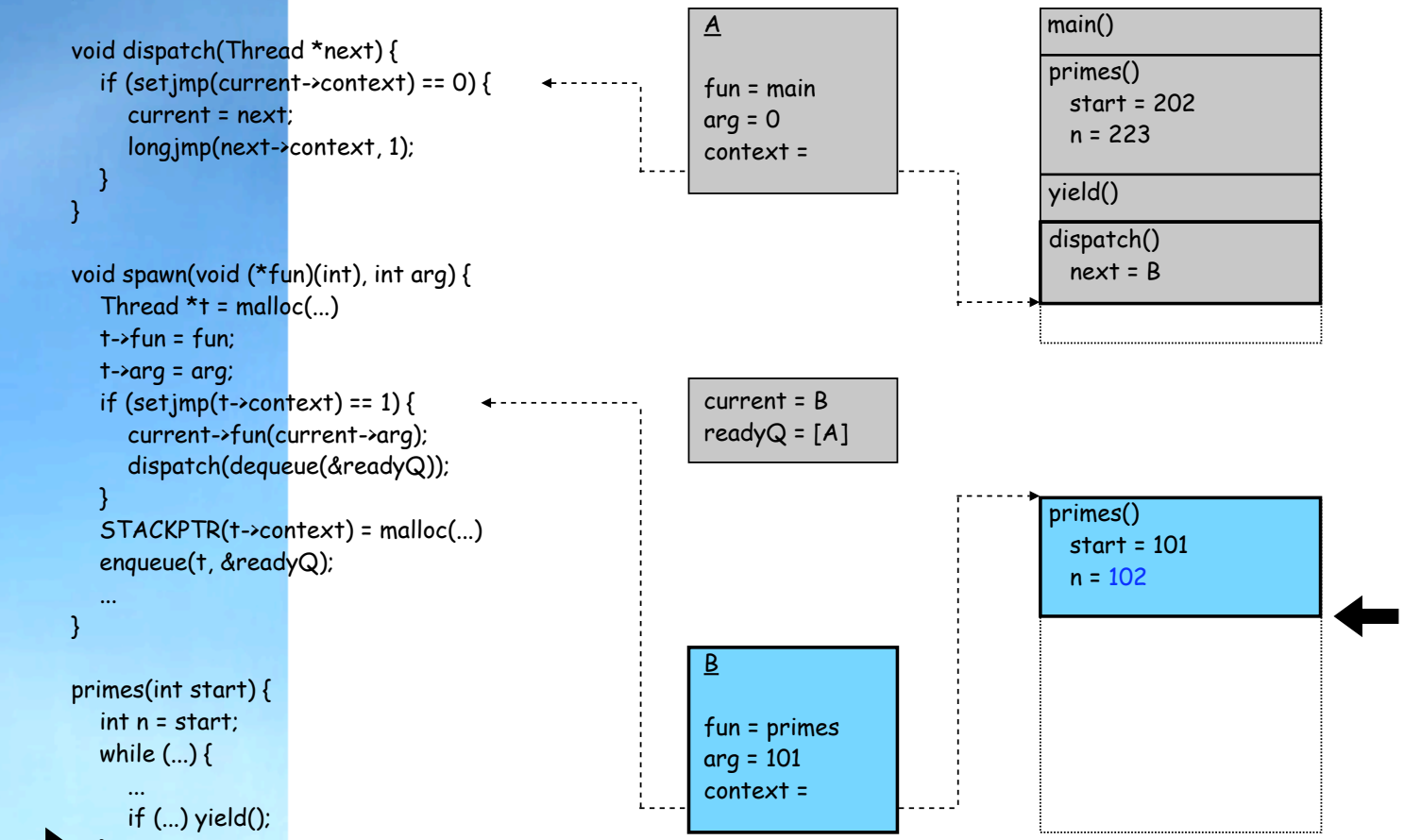

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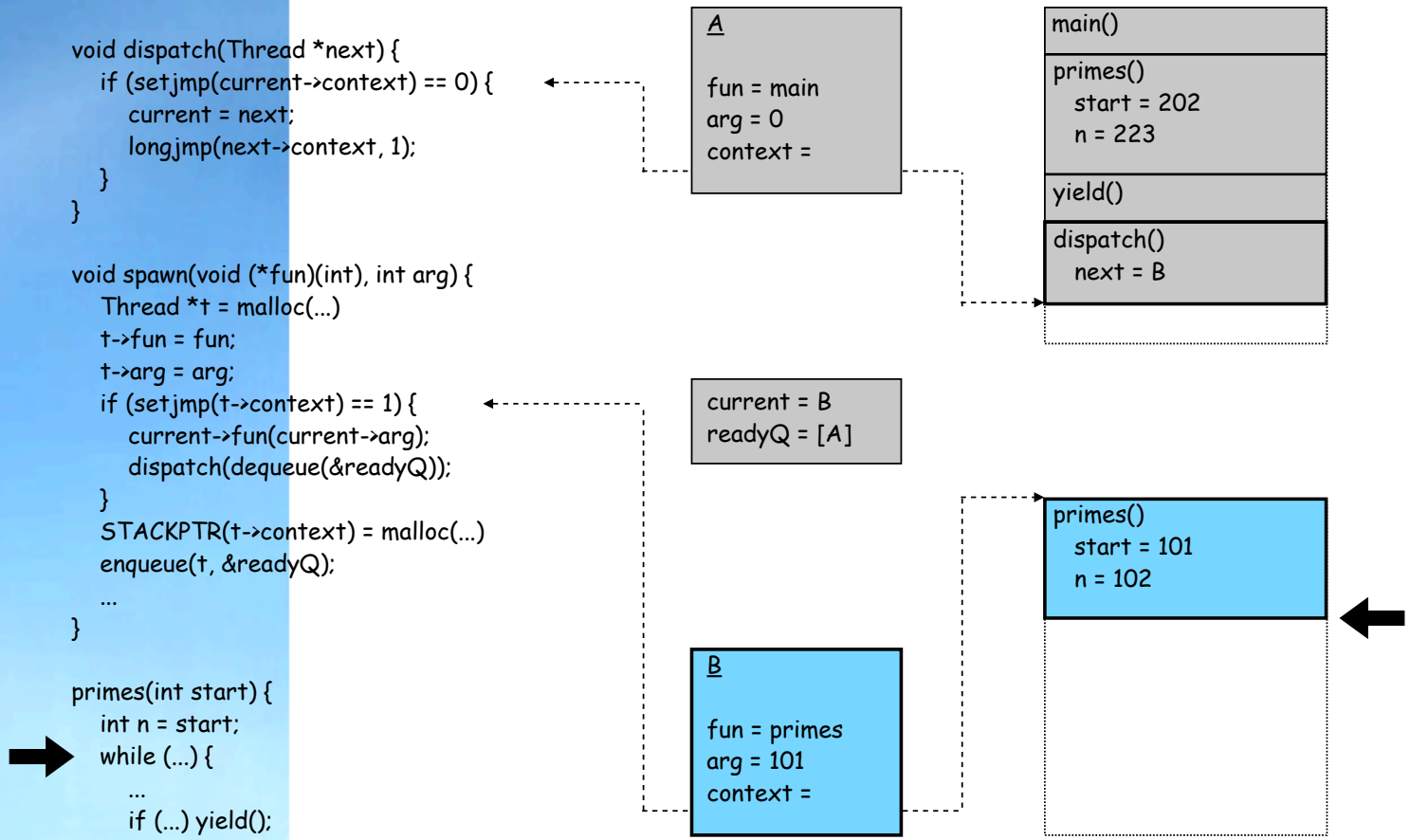

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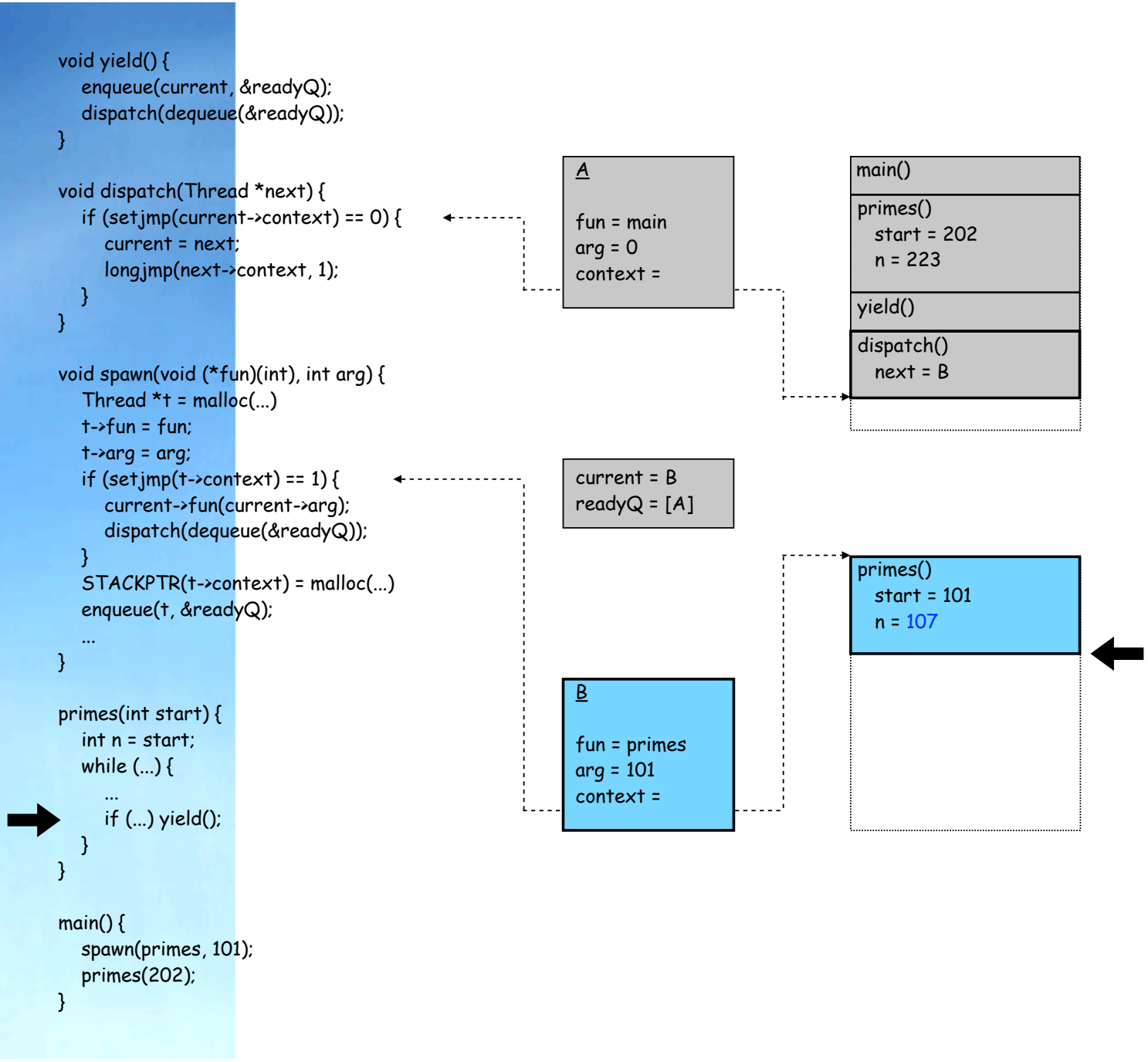

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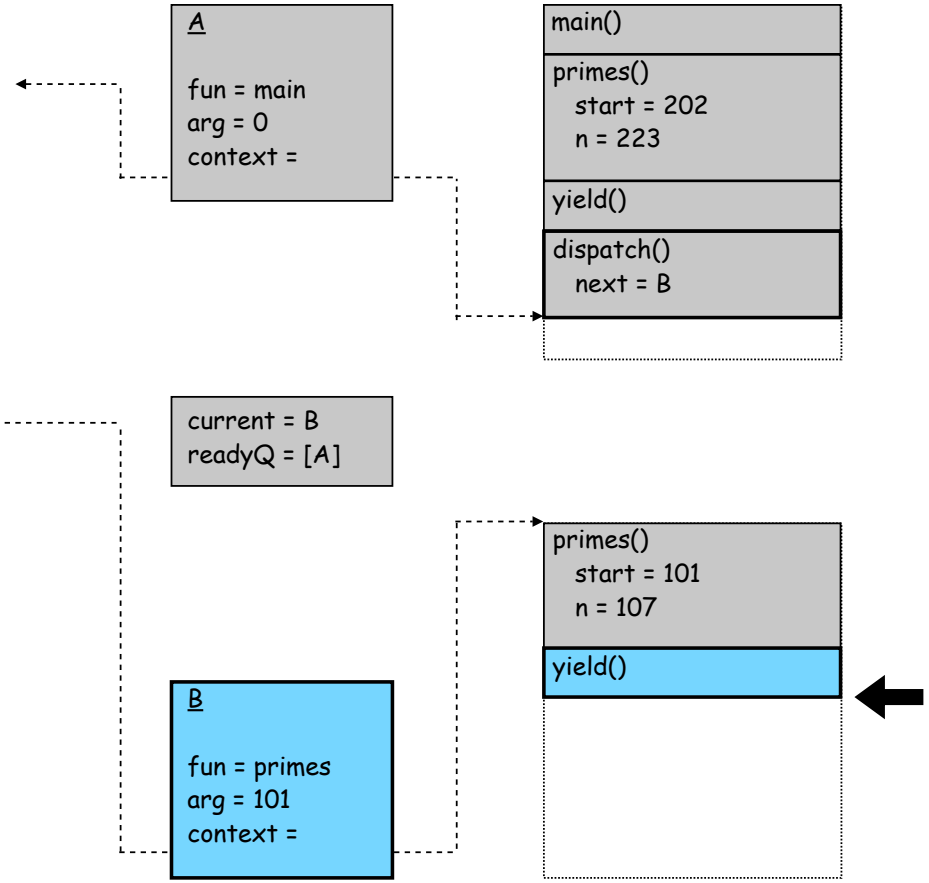

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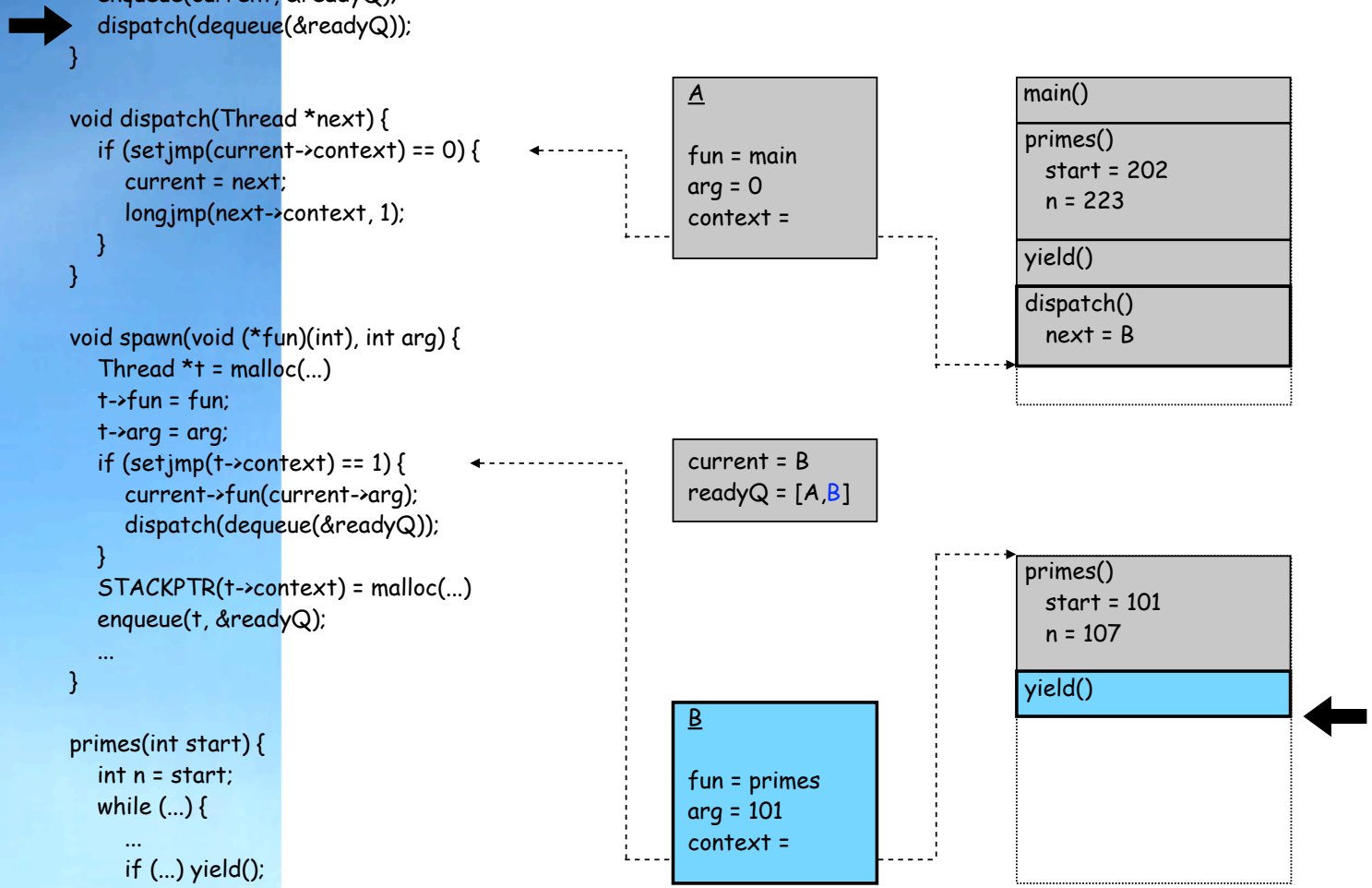

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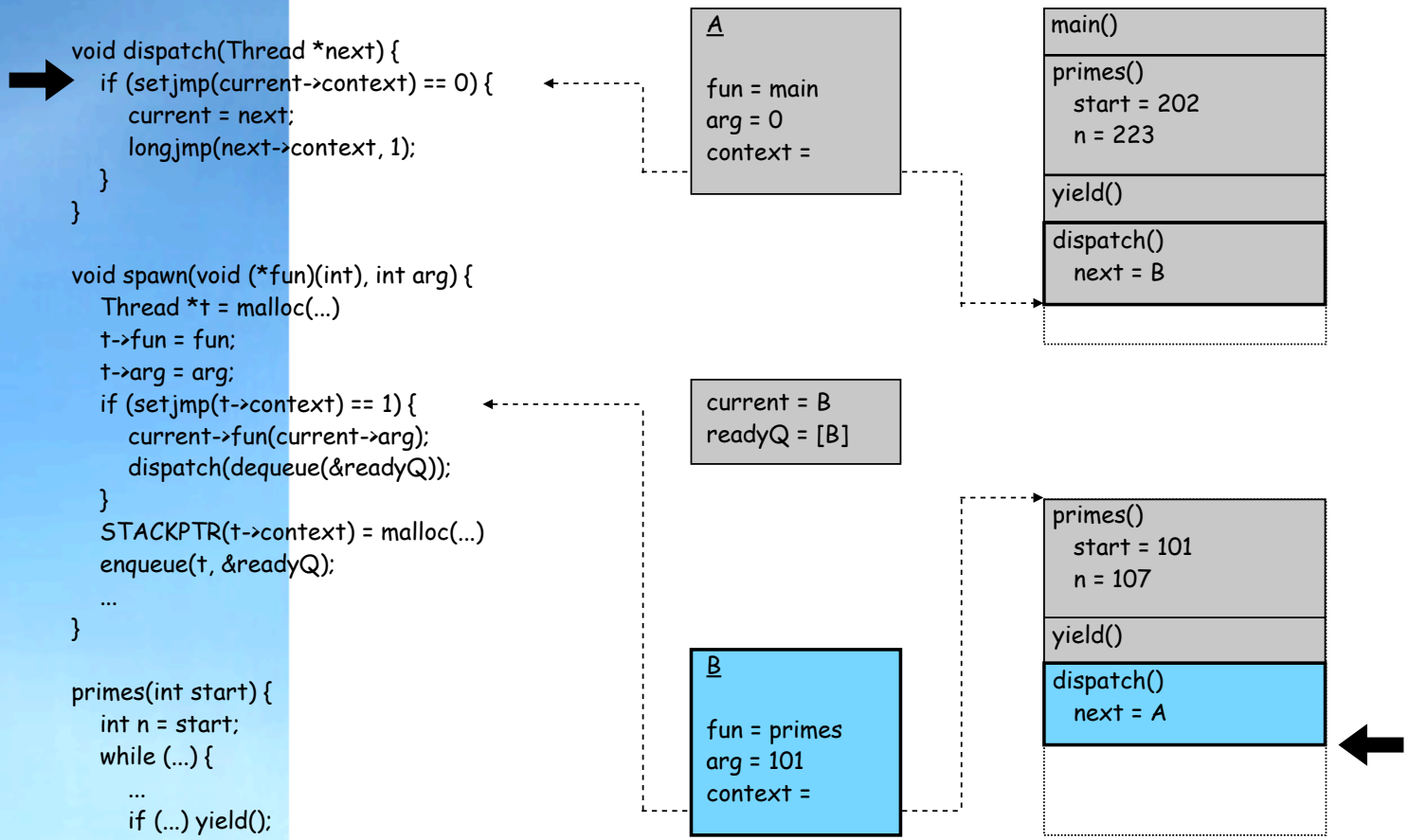

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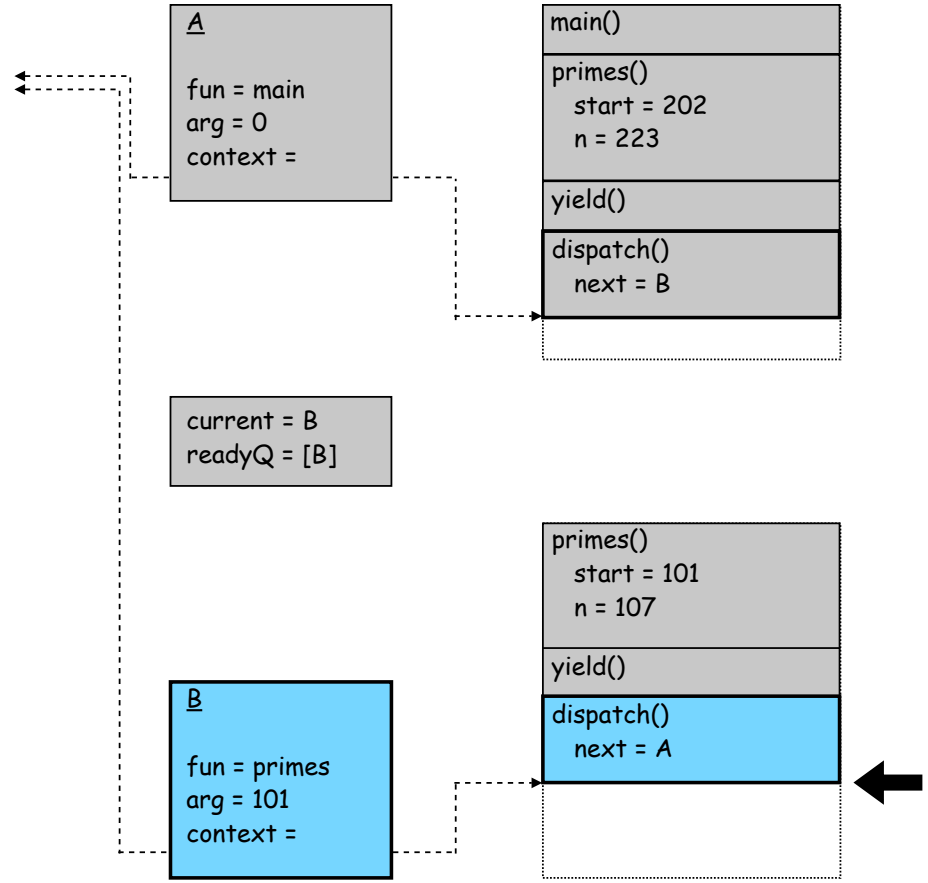

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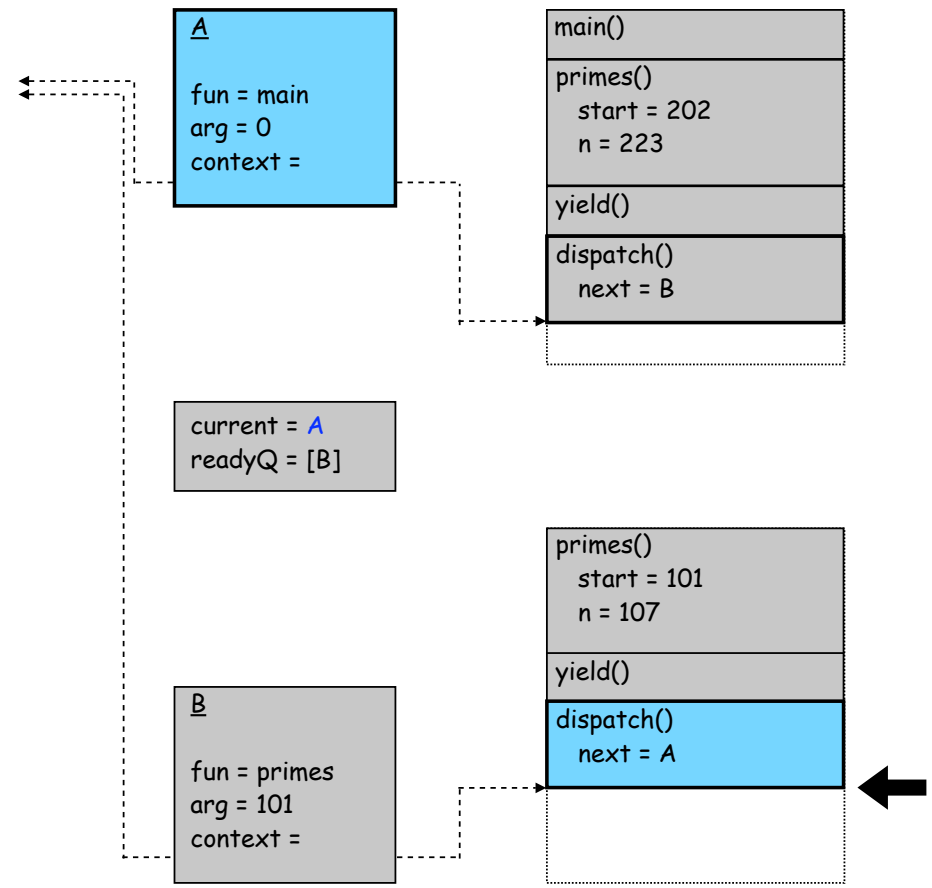

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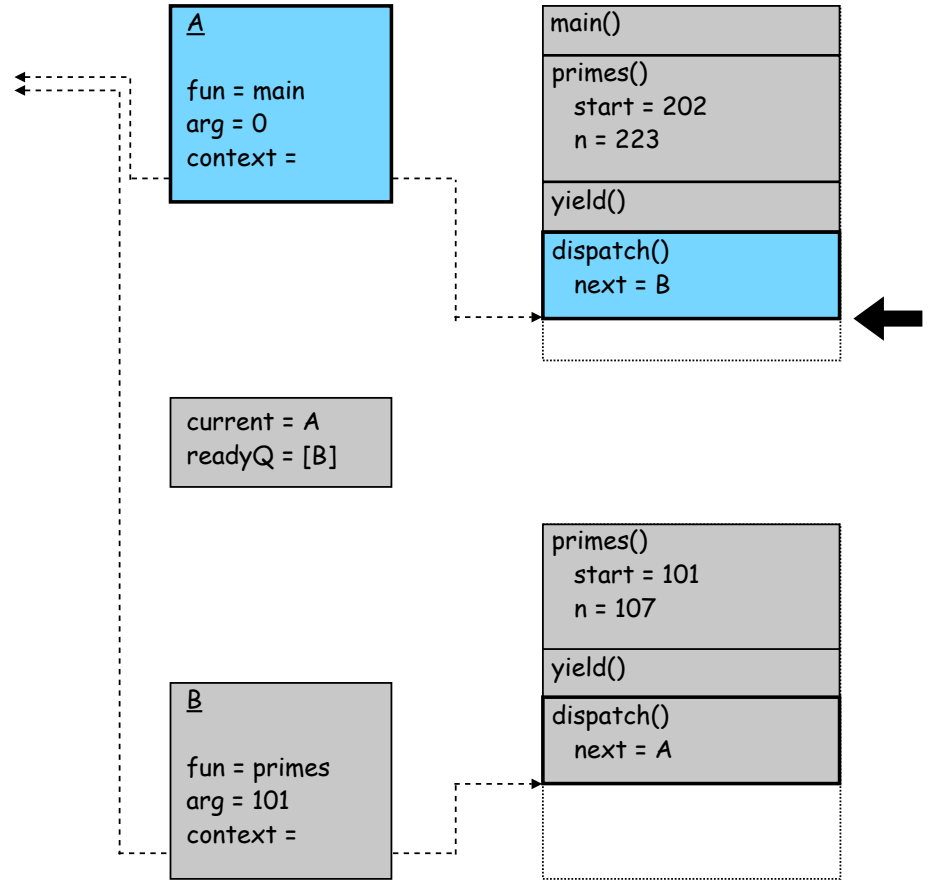

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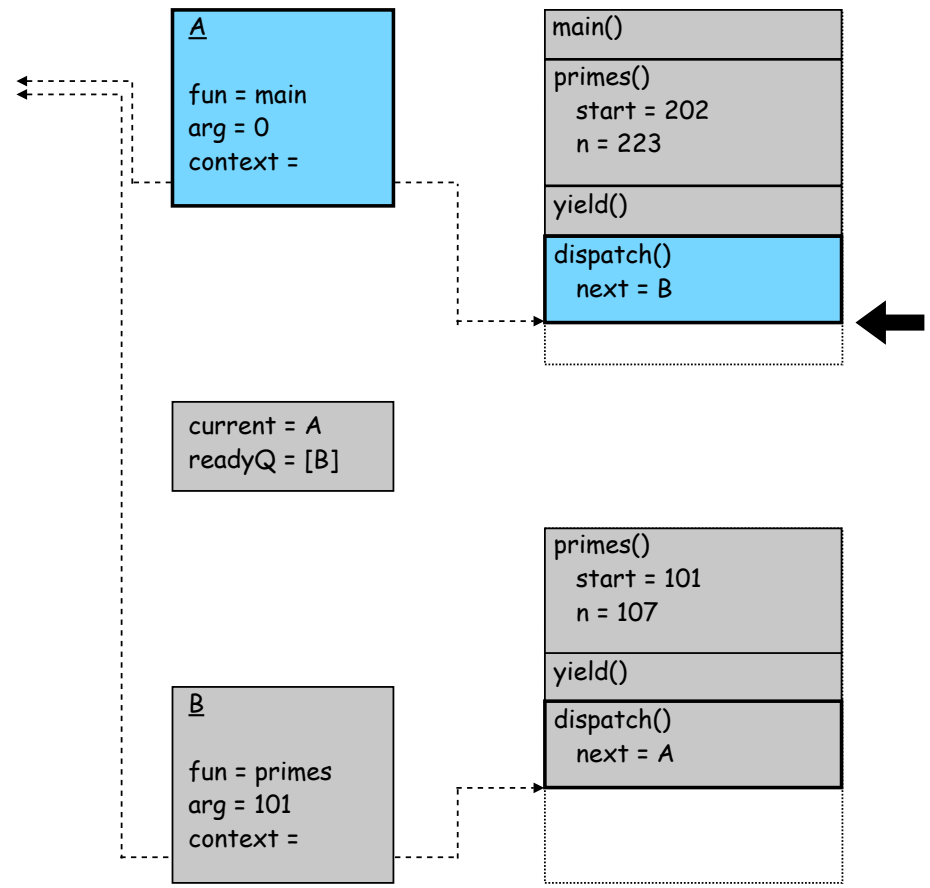

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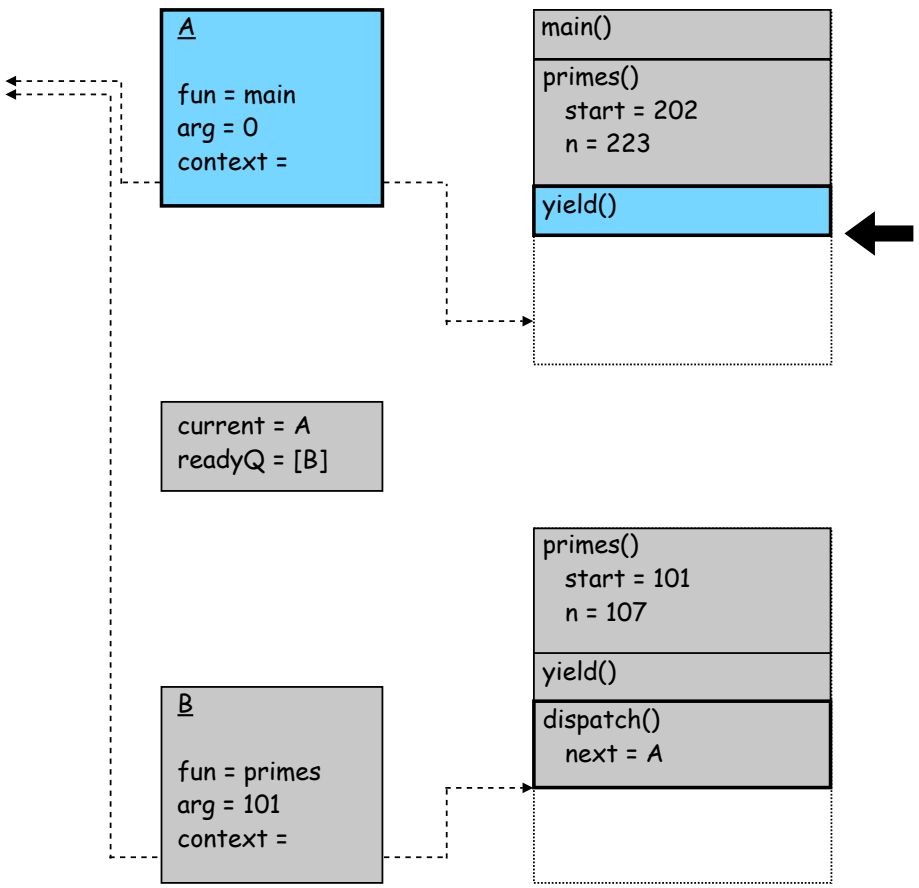

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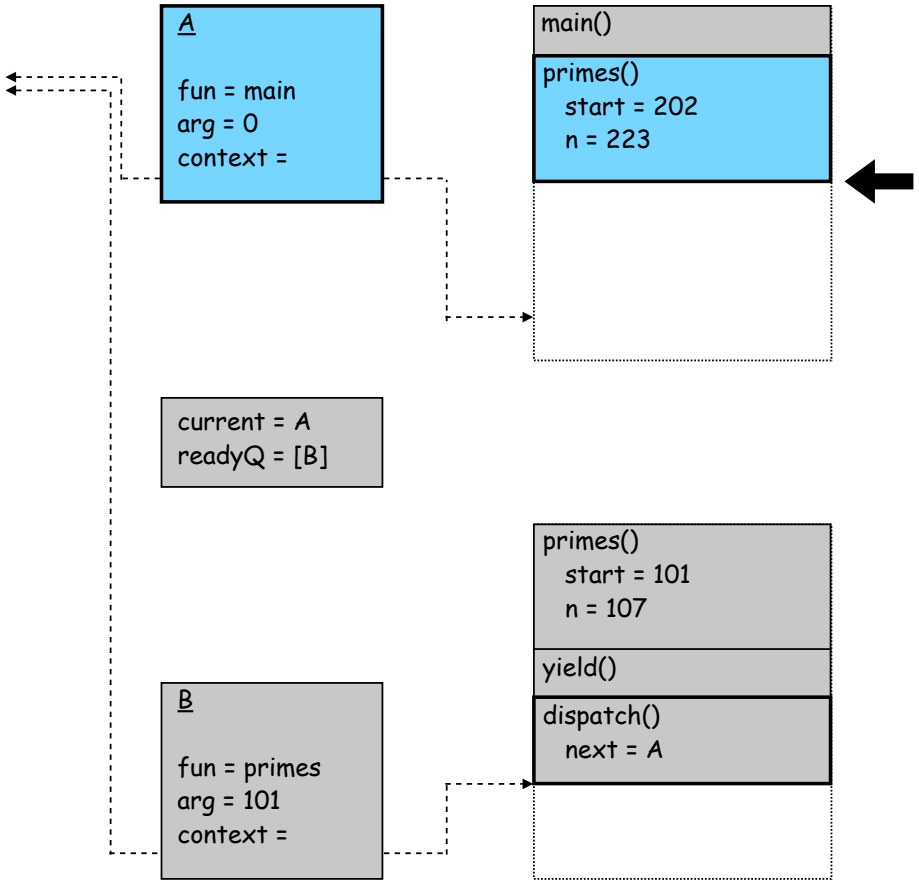

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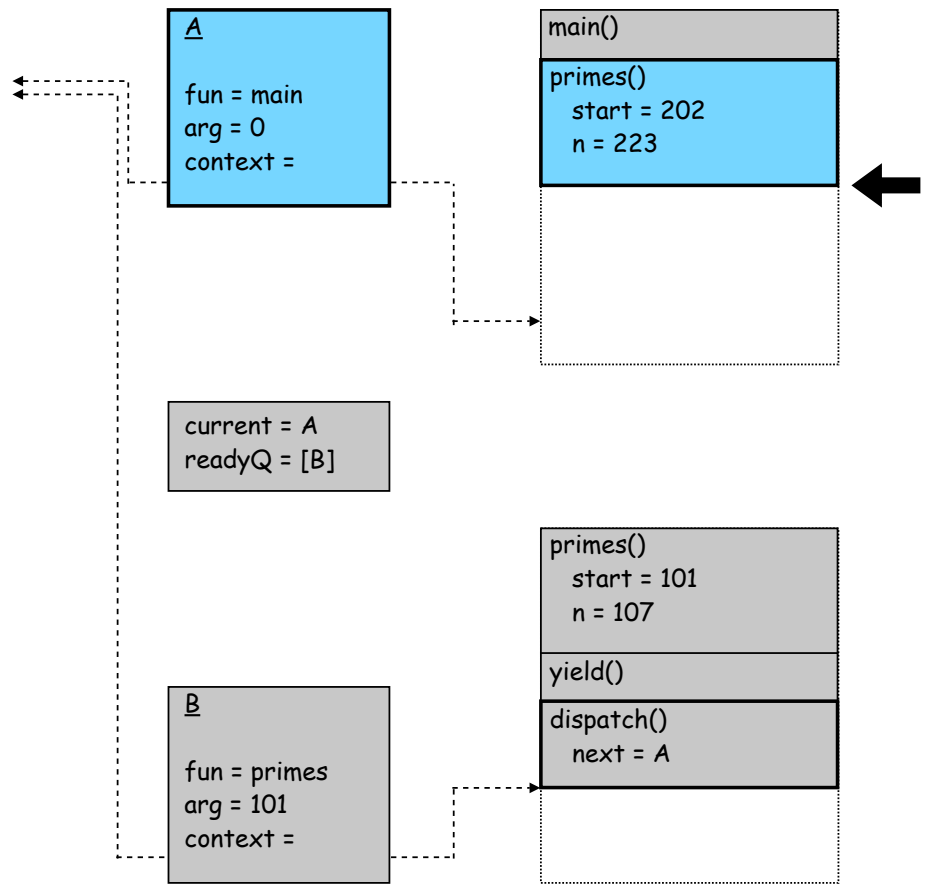

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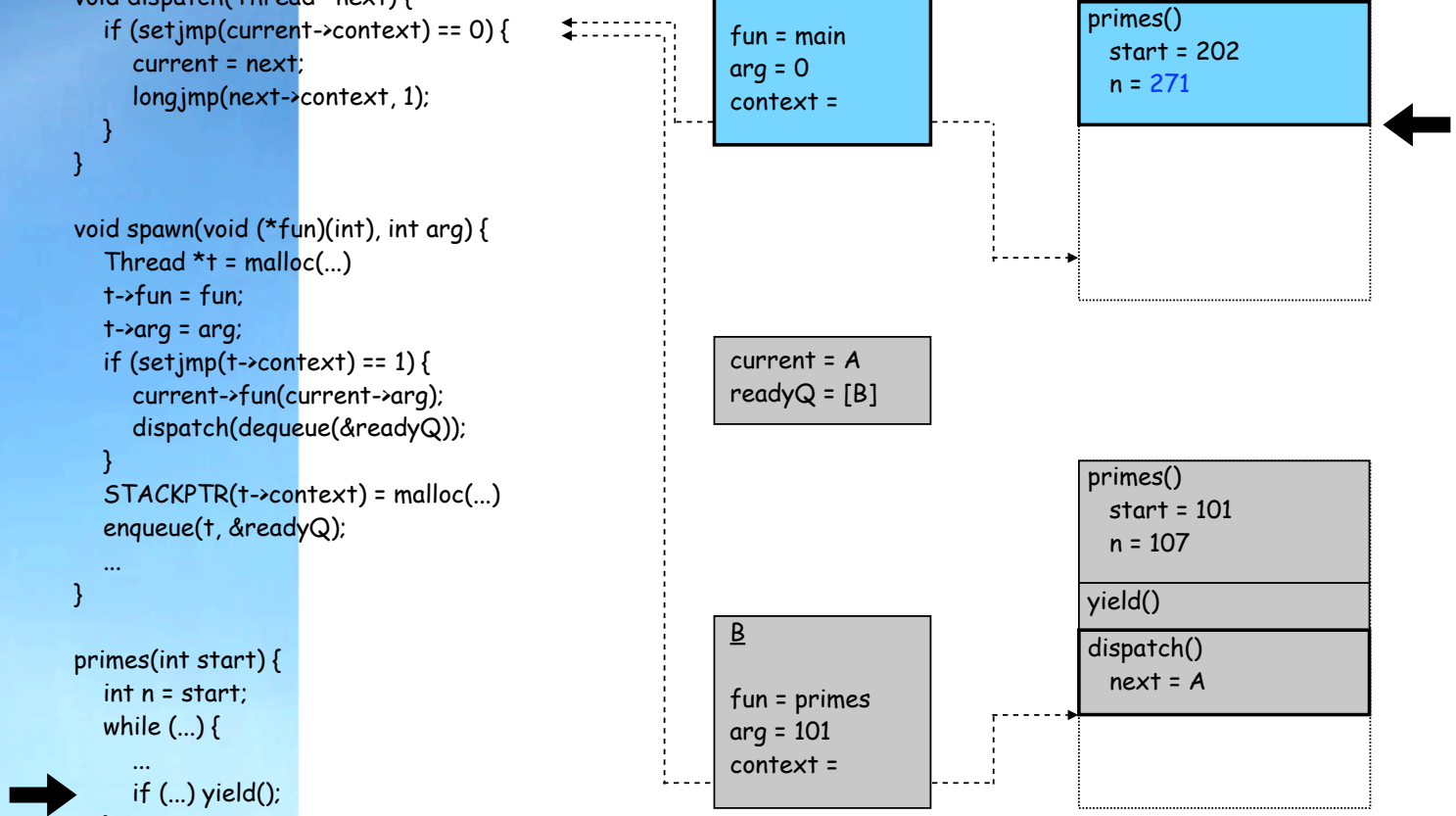

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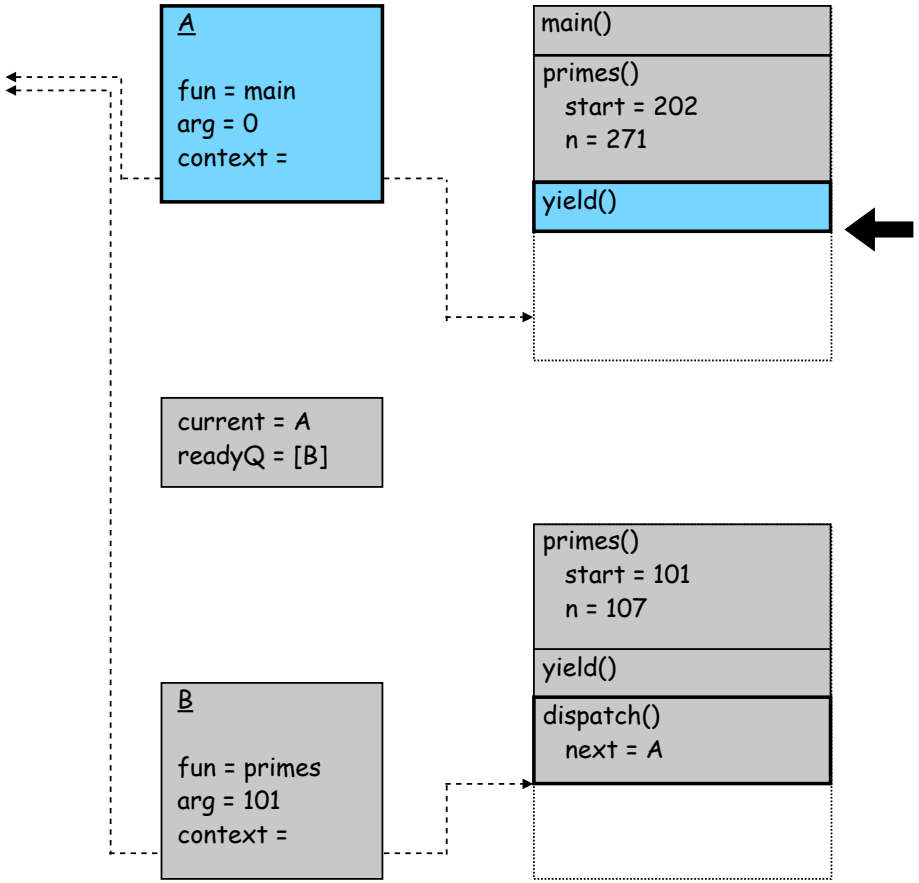

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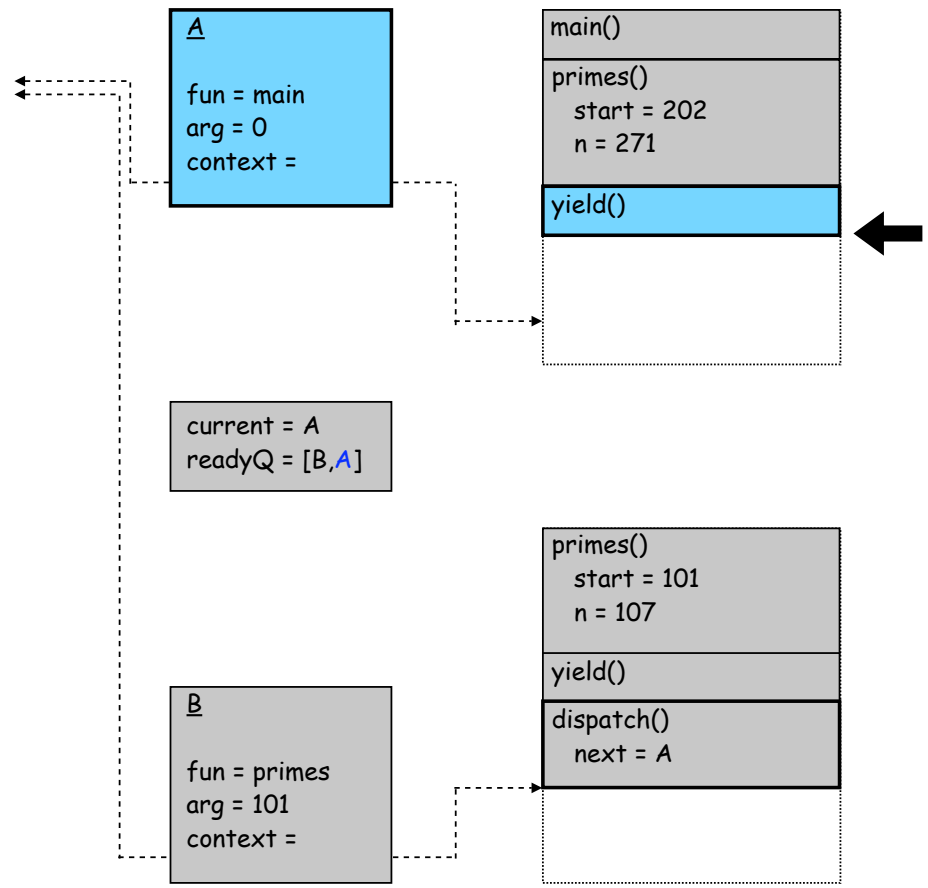

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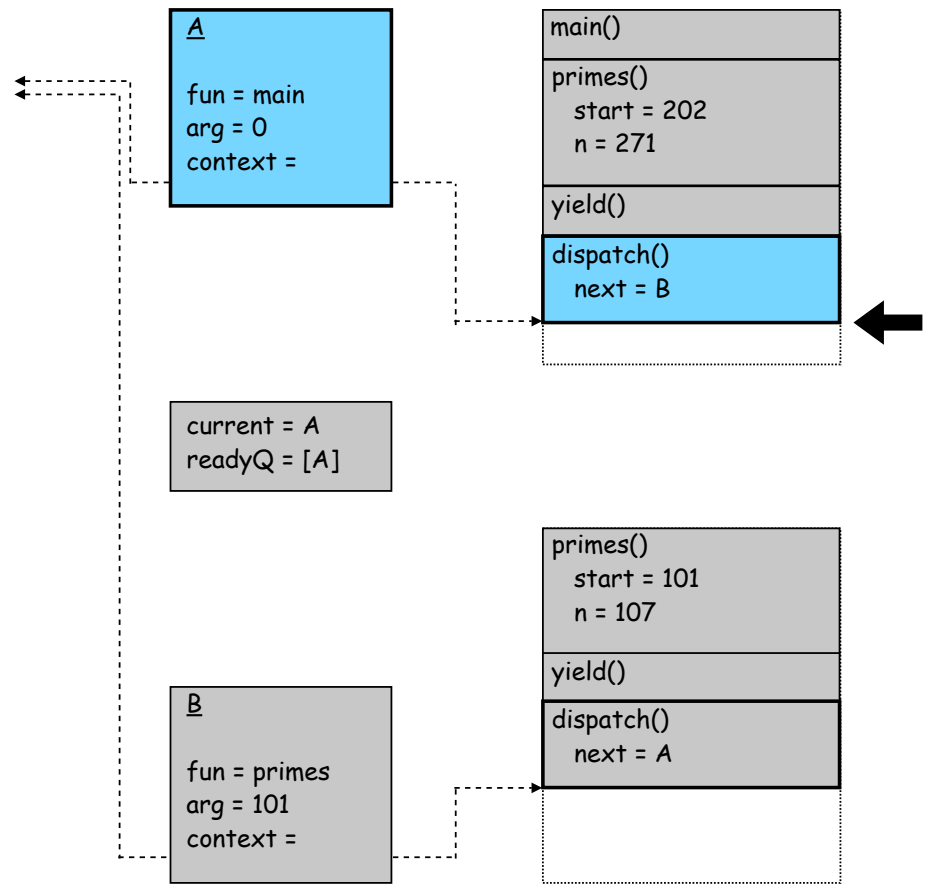

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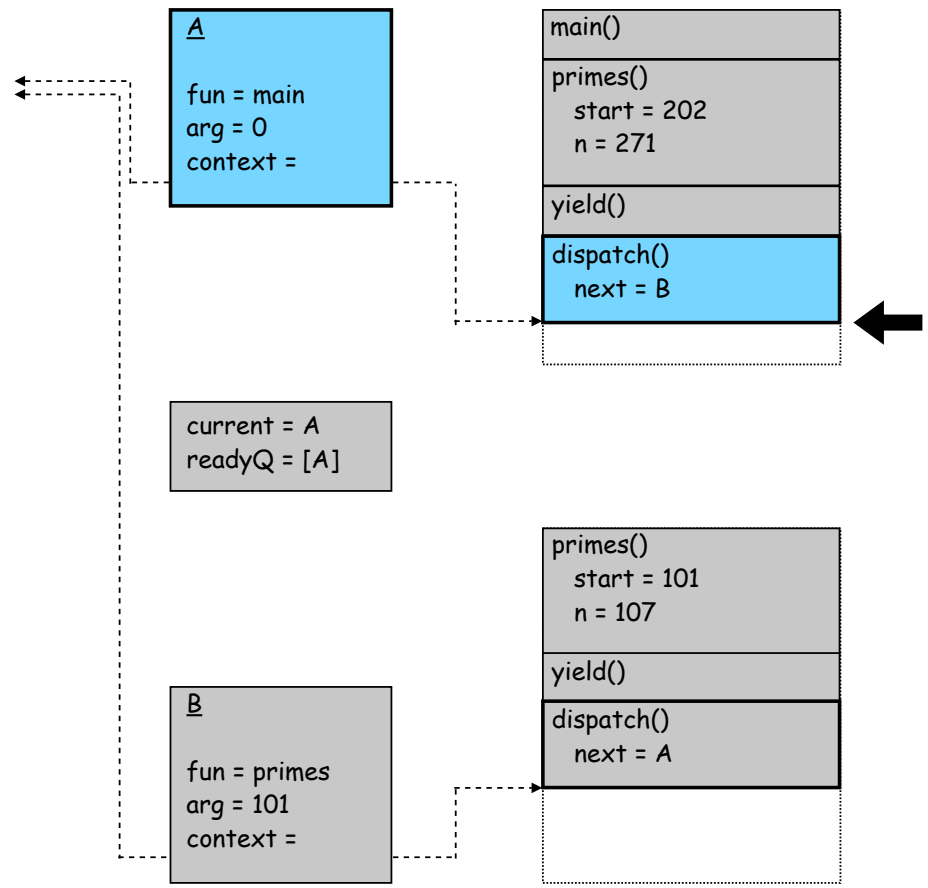

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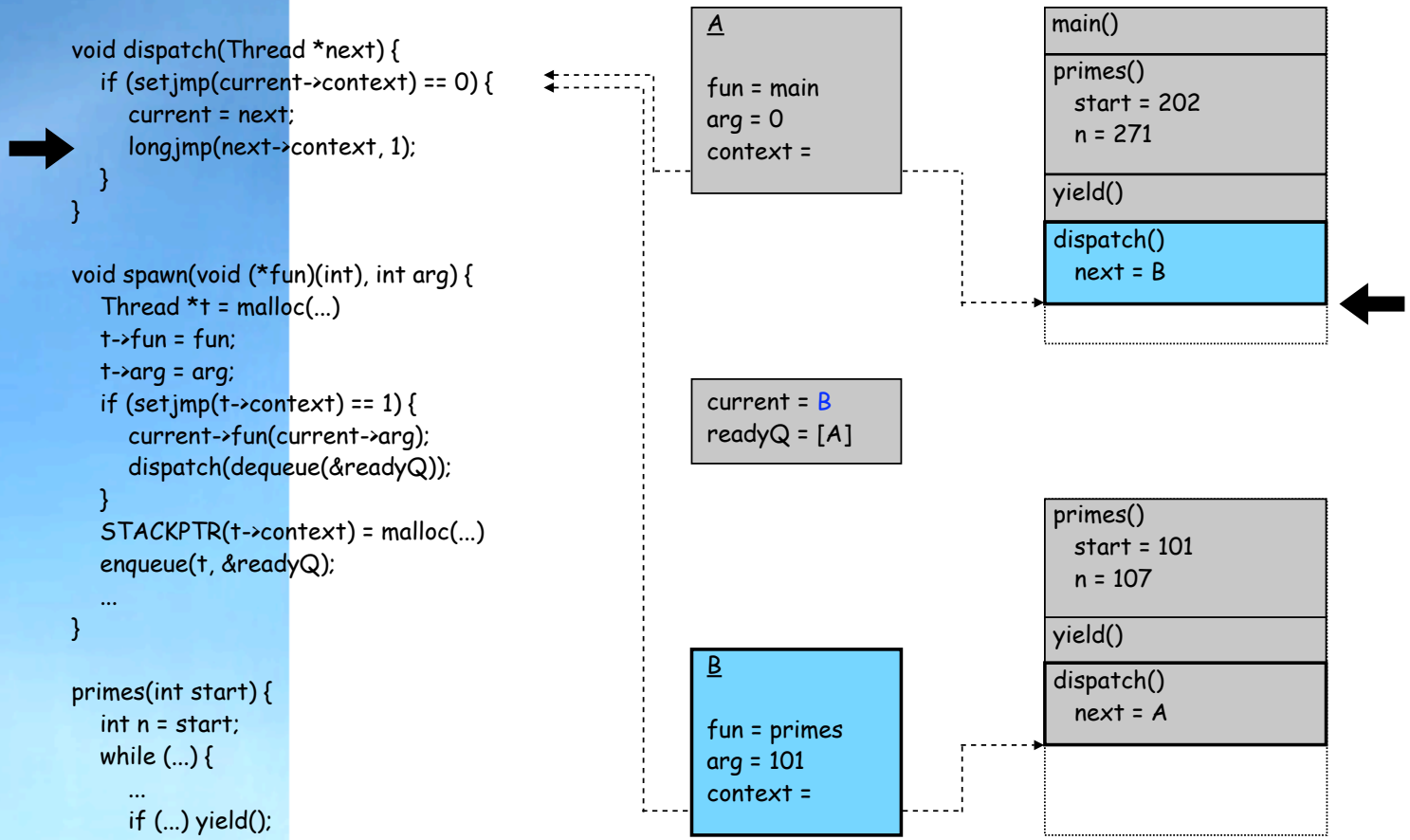

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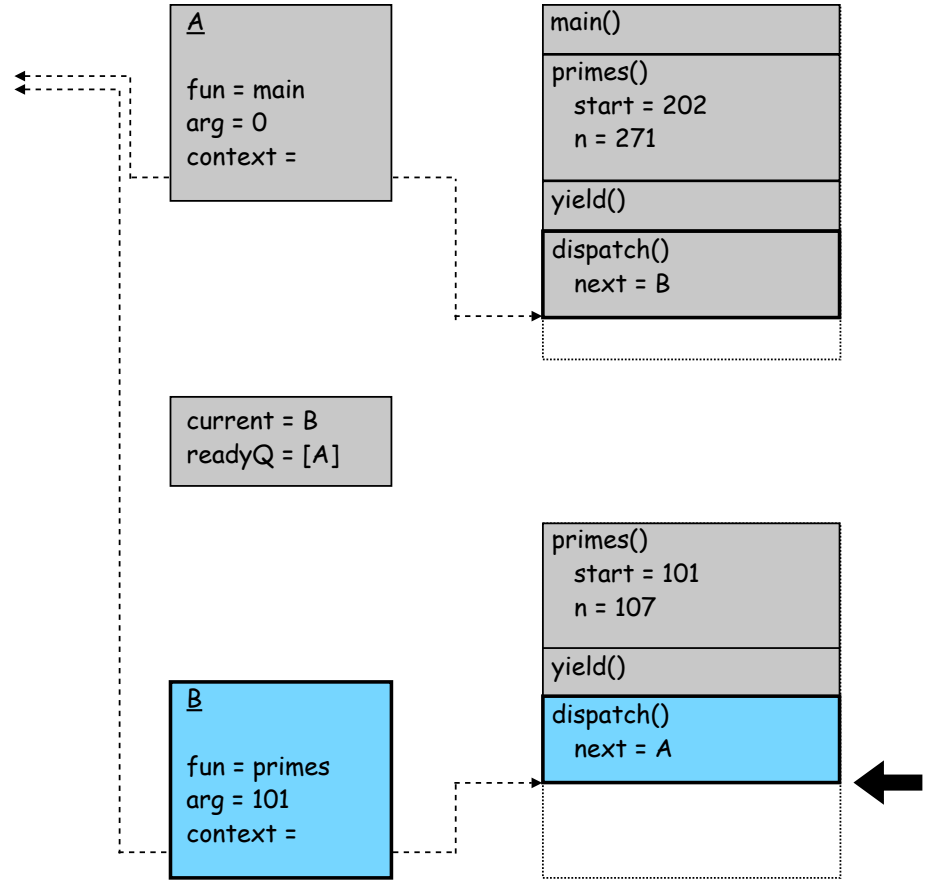

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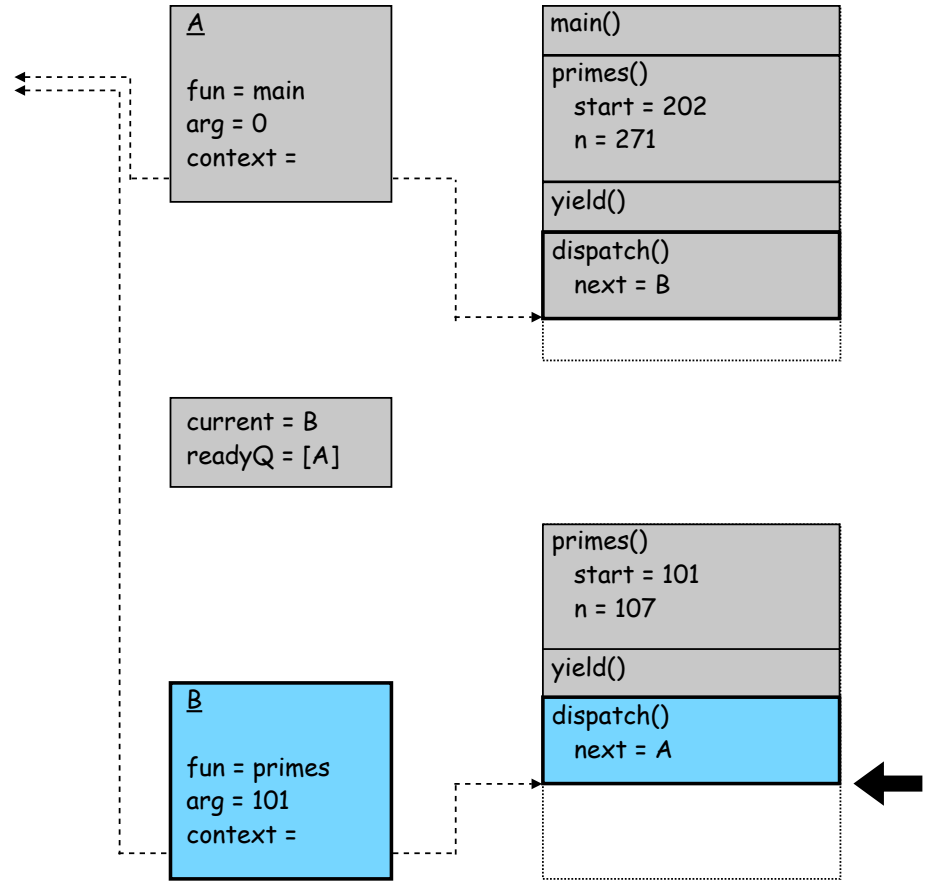

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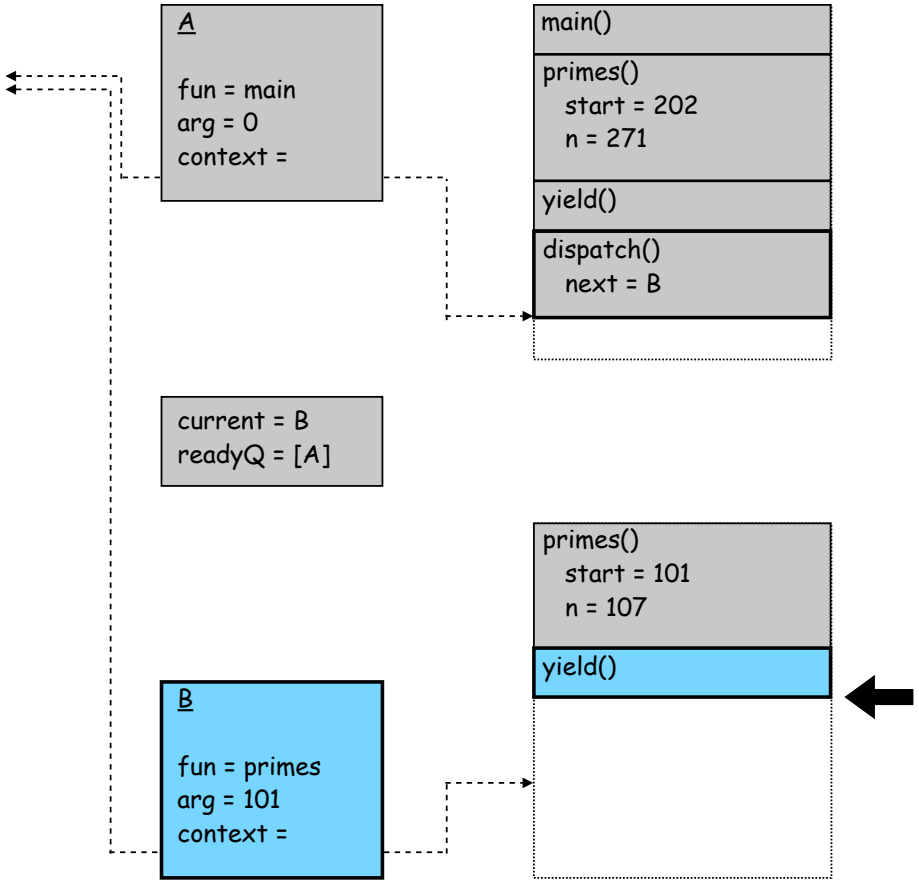

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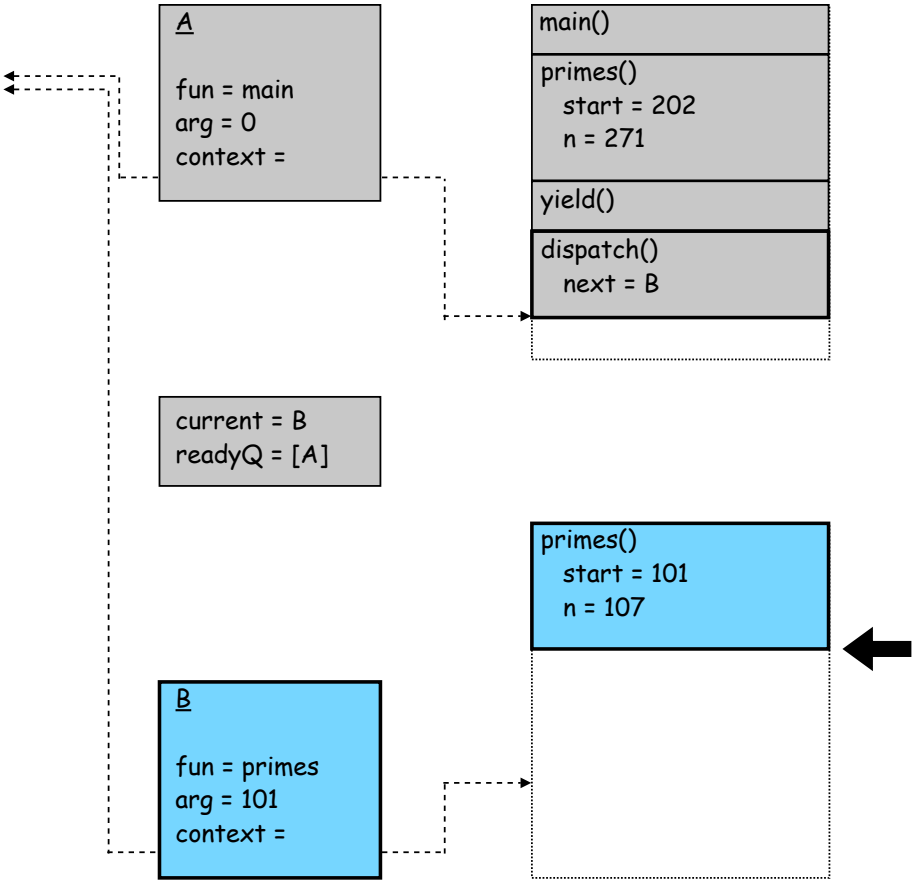

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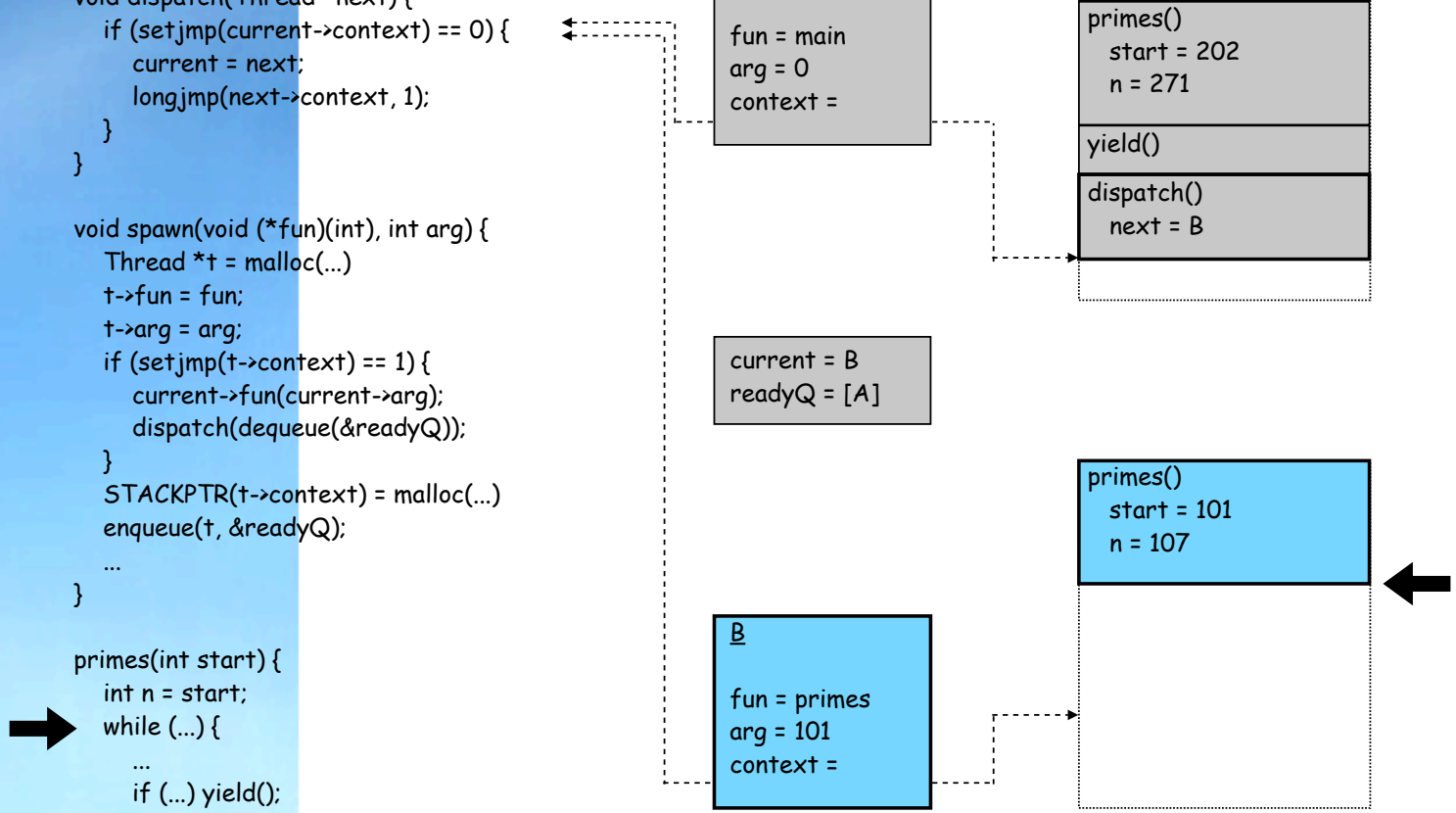

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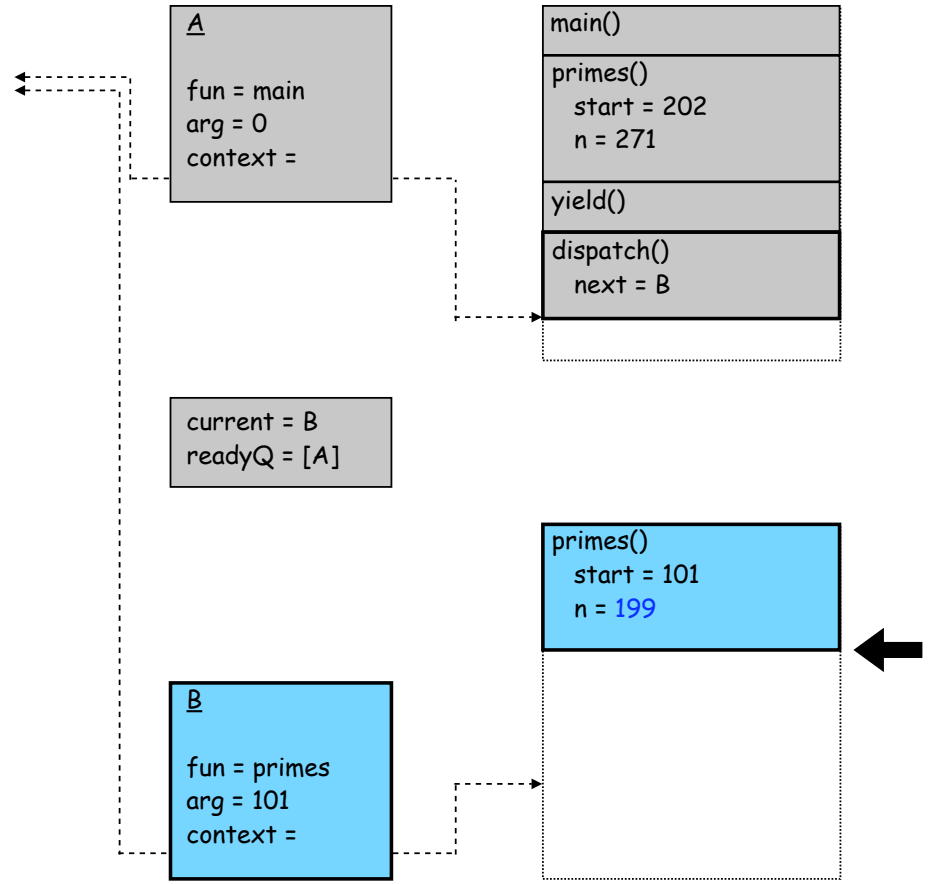

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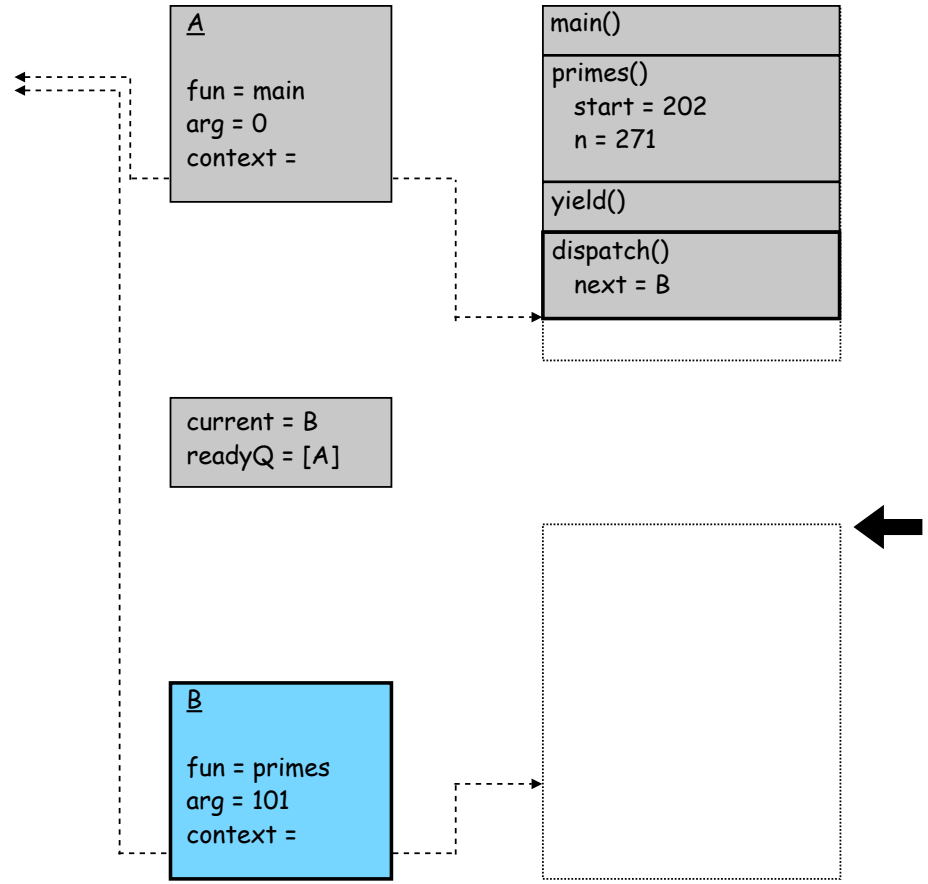

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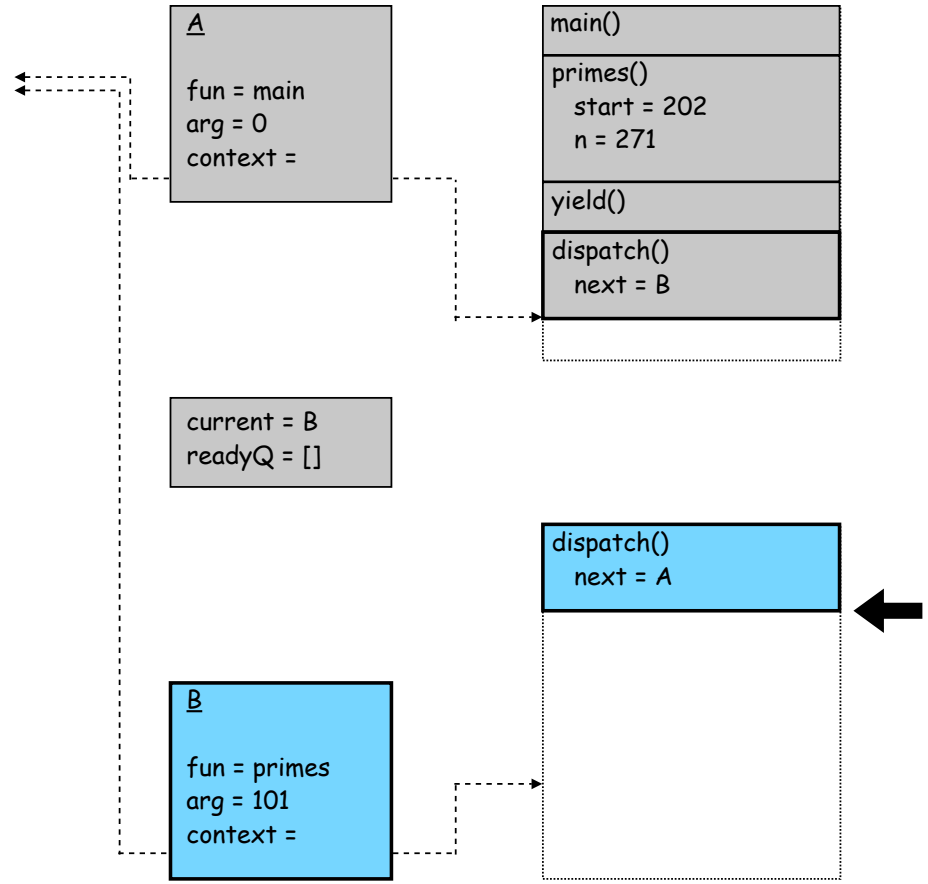

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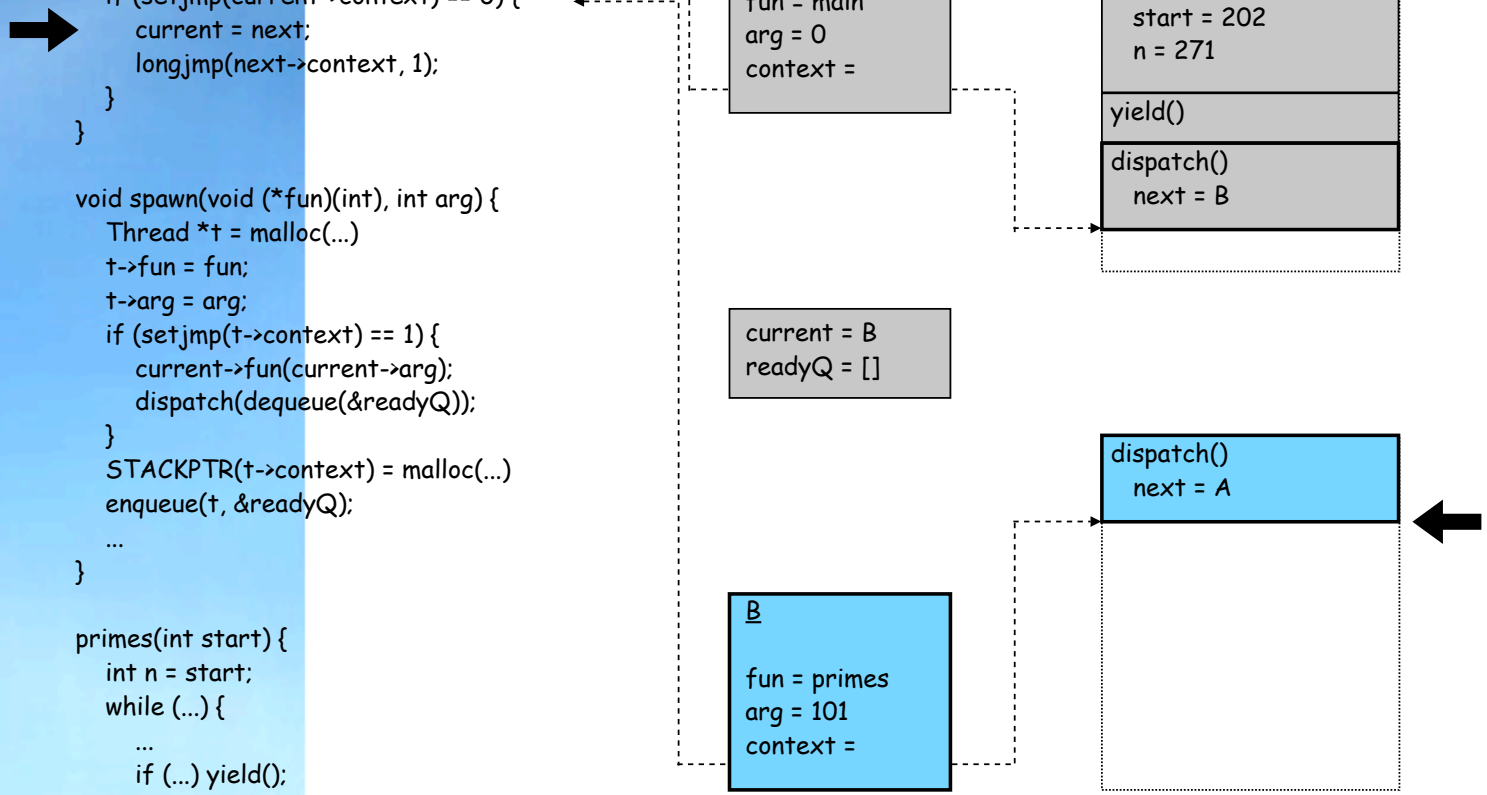

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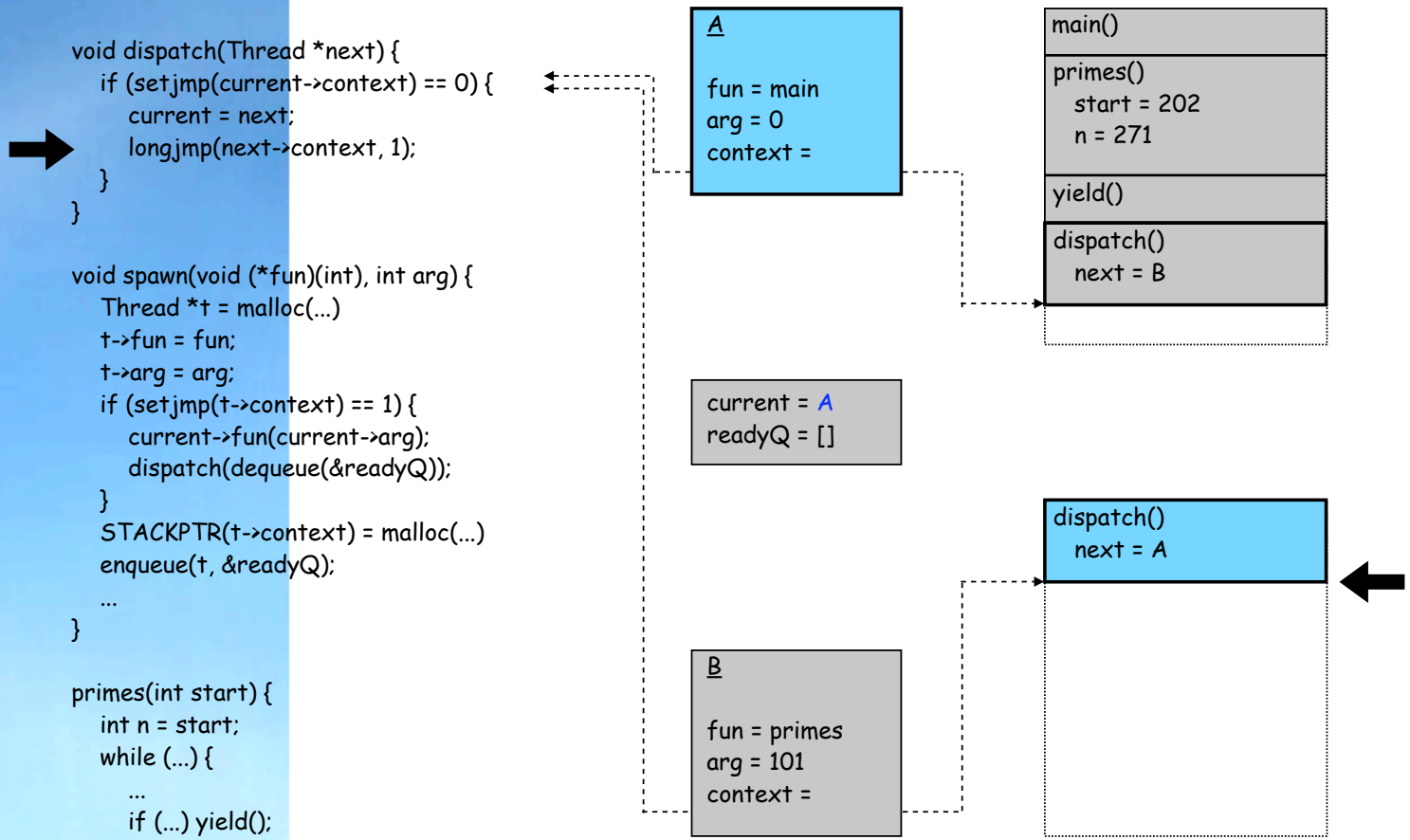

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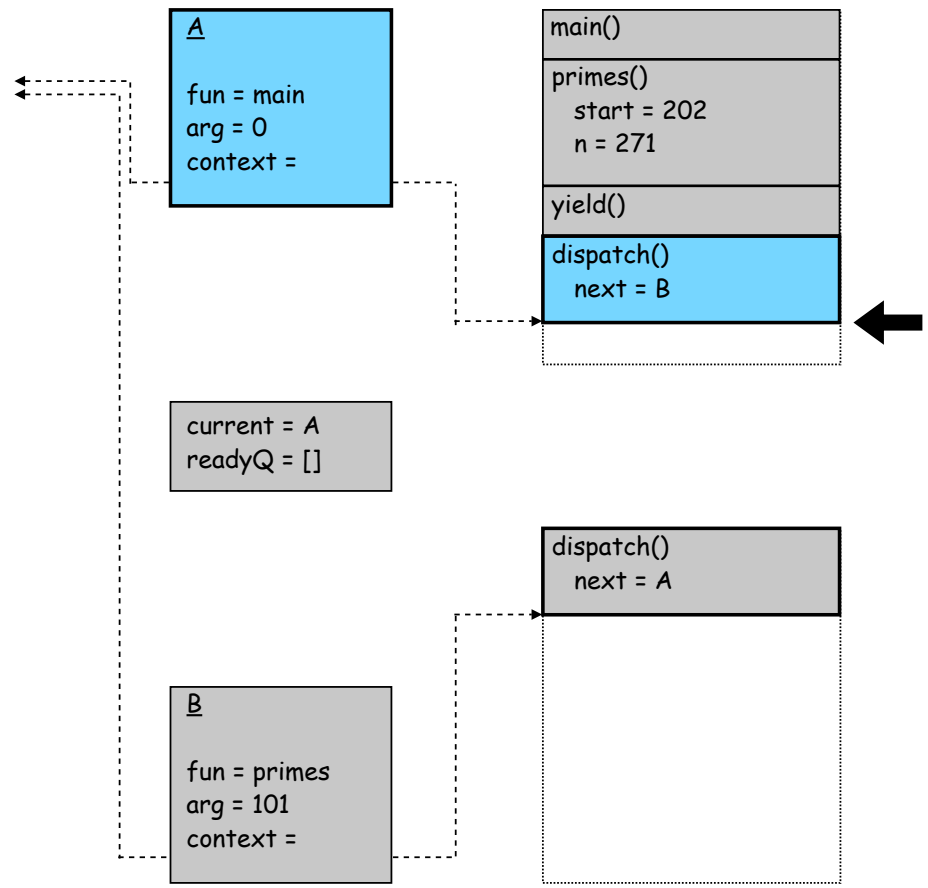

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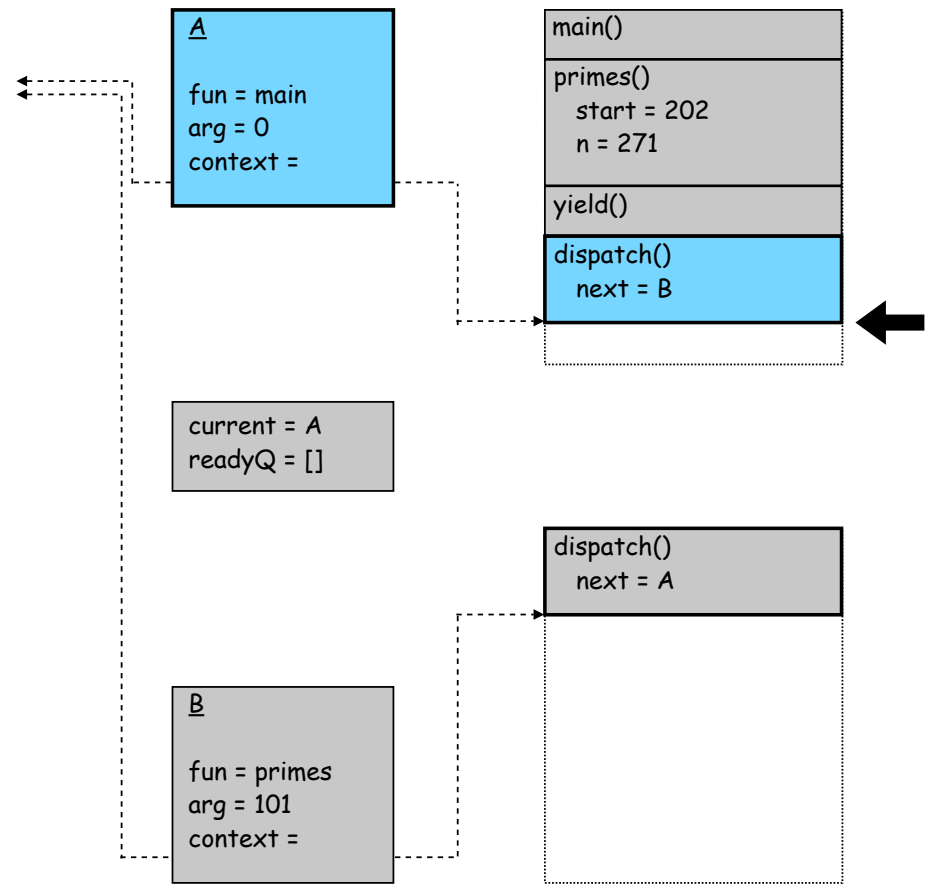

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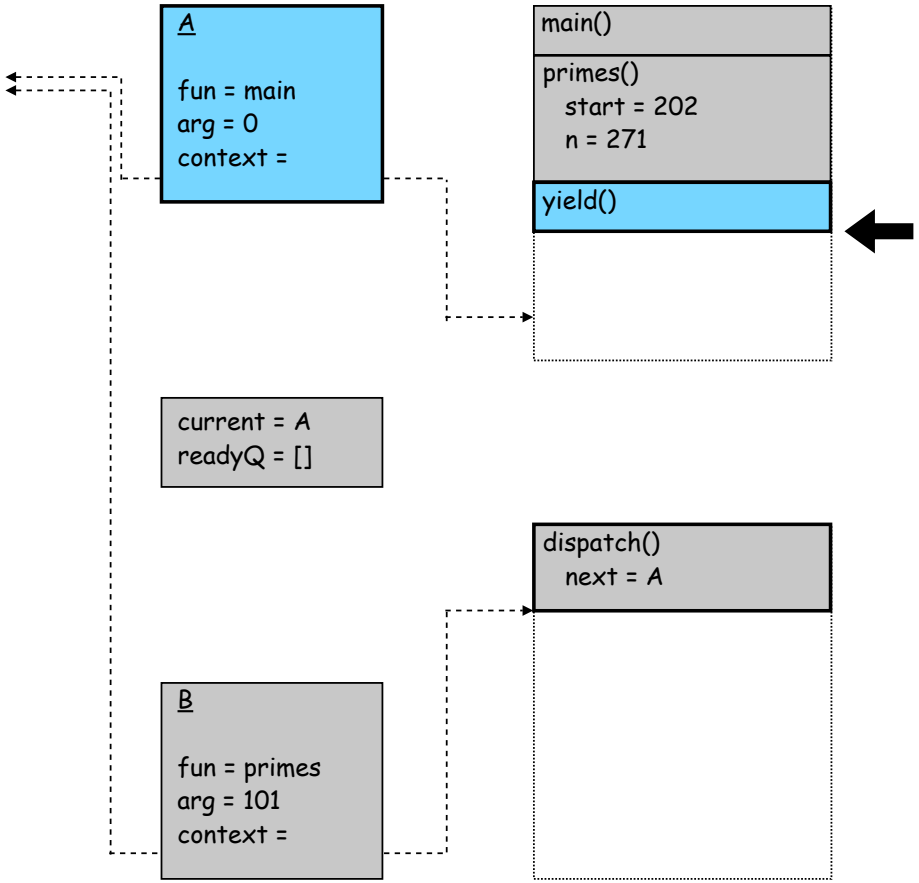

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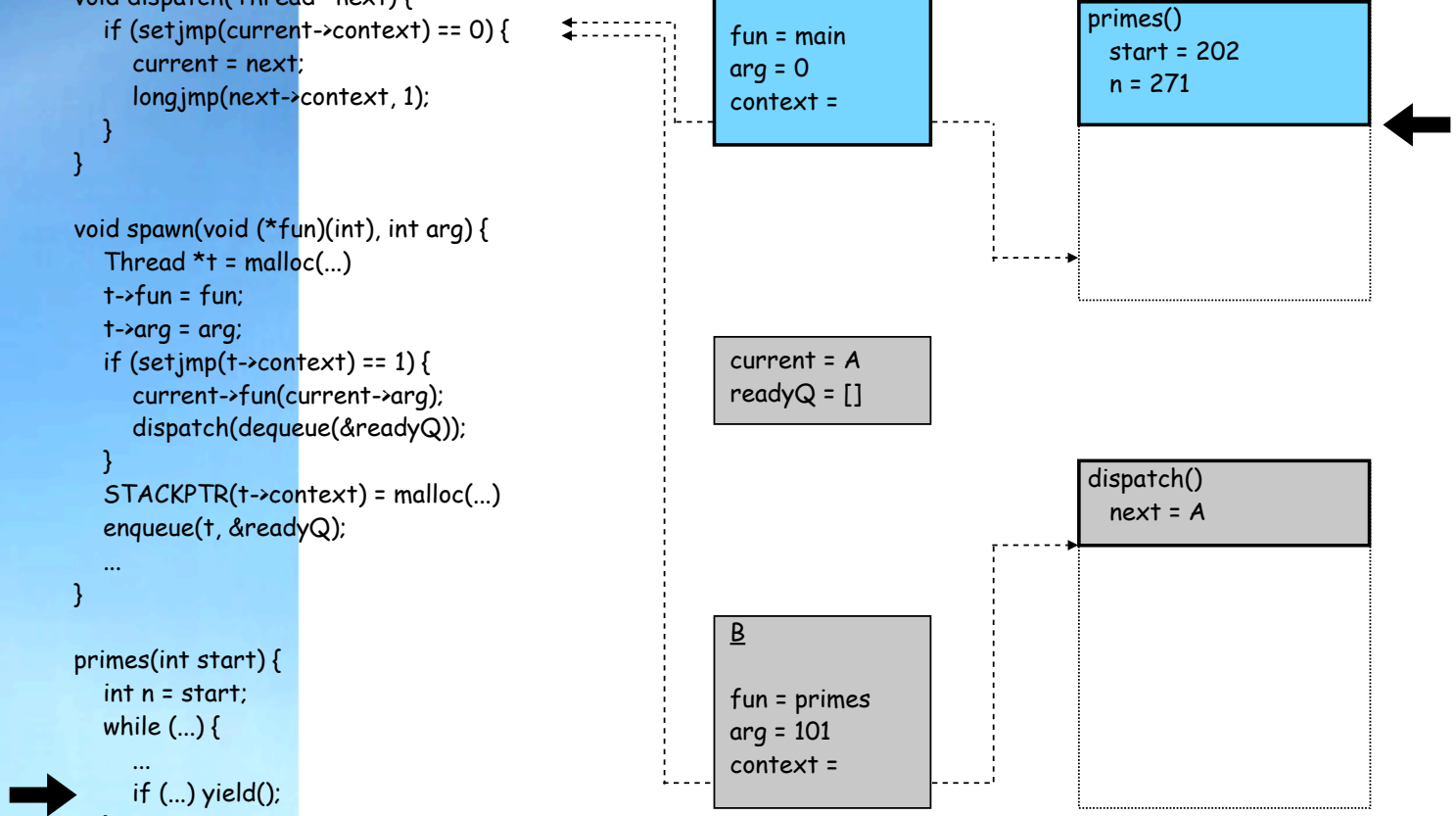

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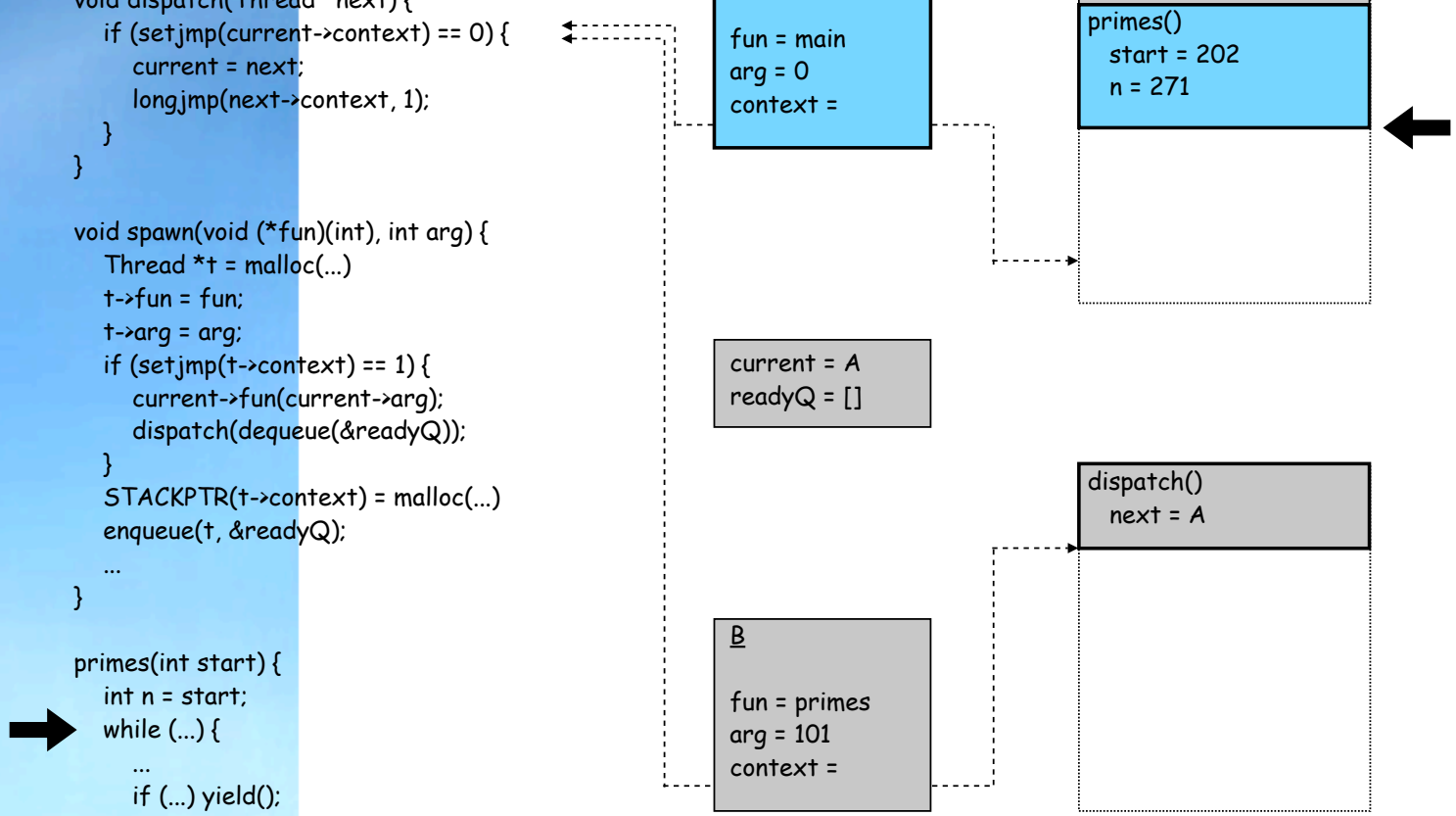

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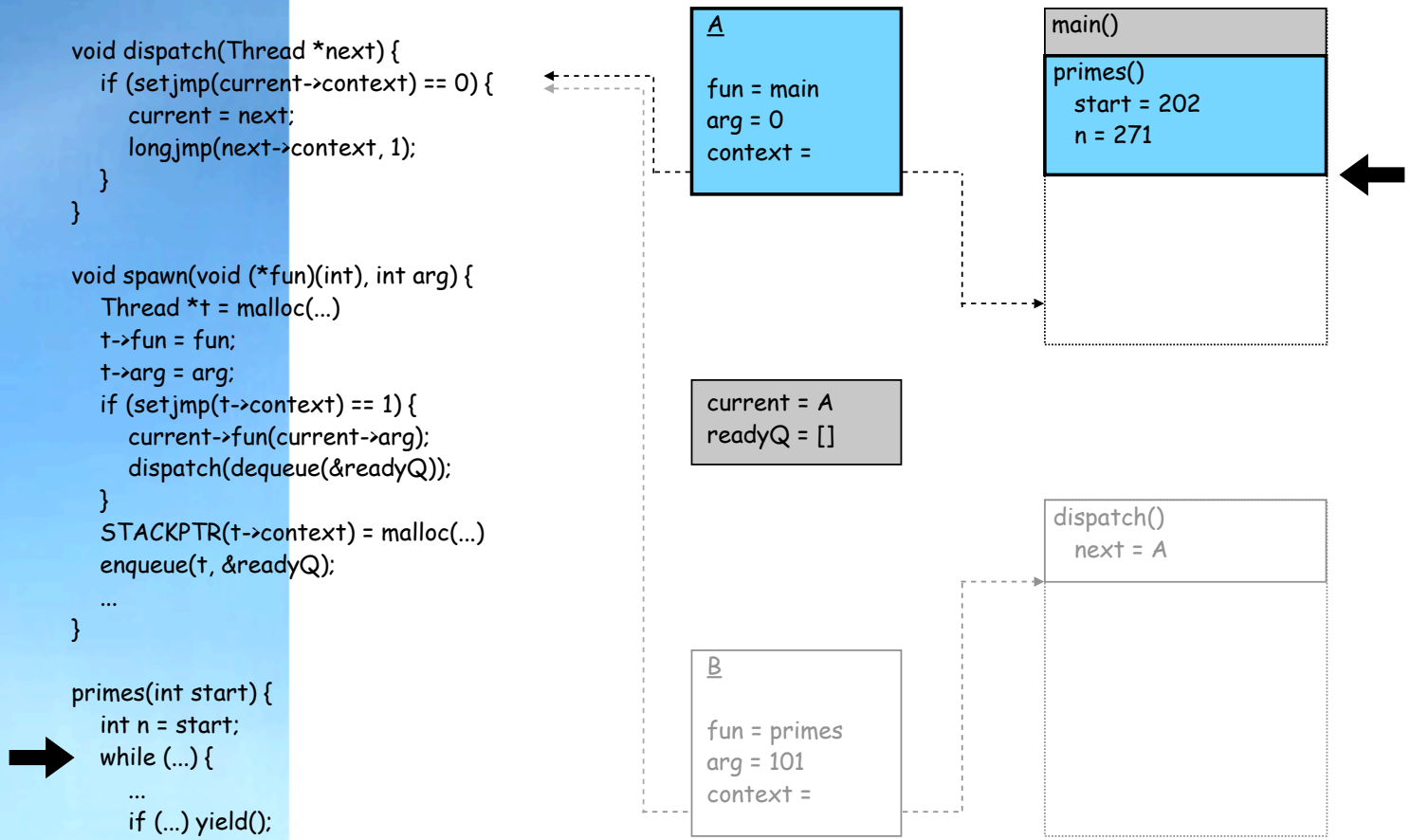
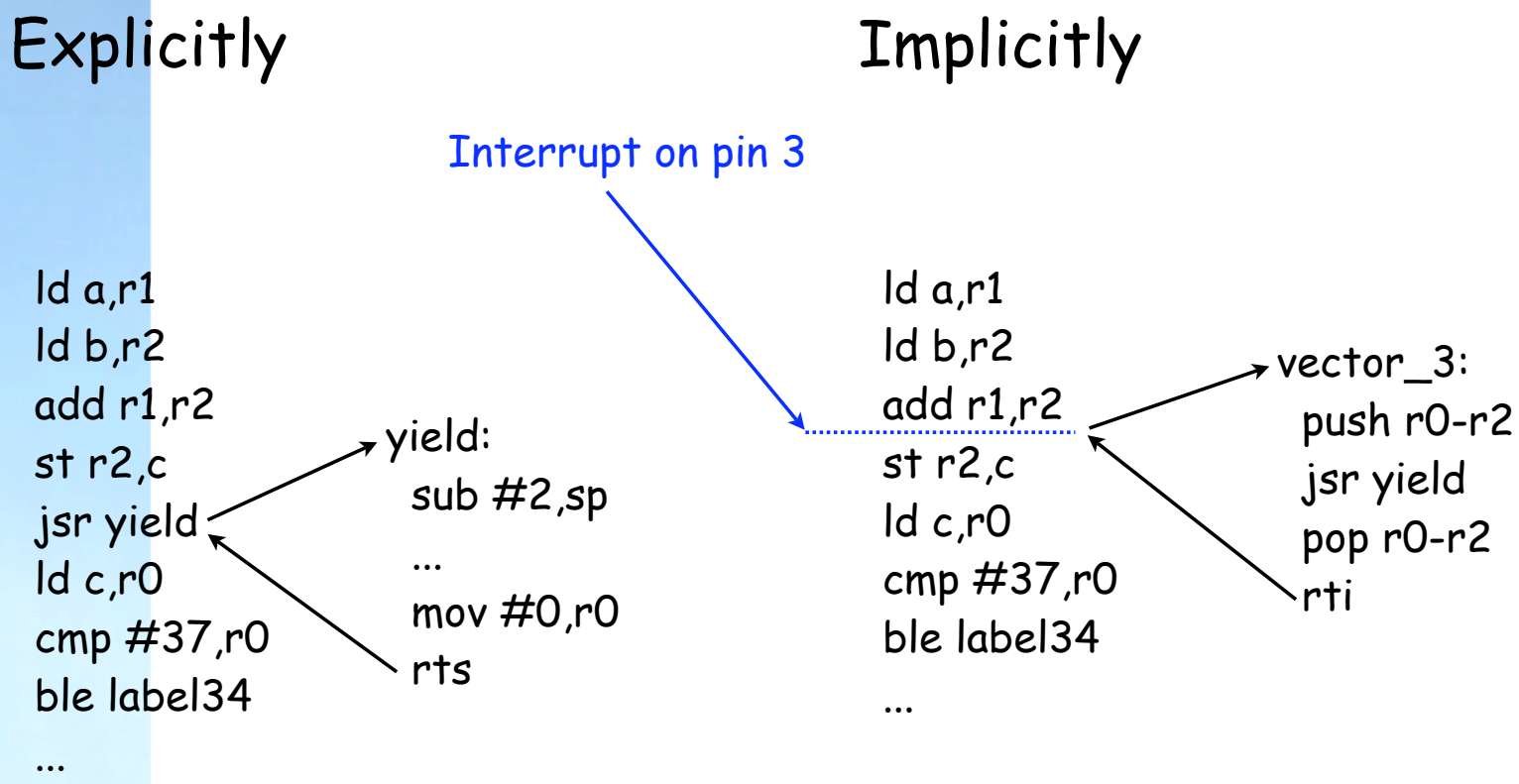


Calling yield()



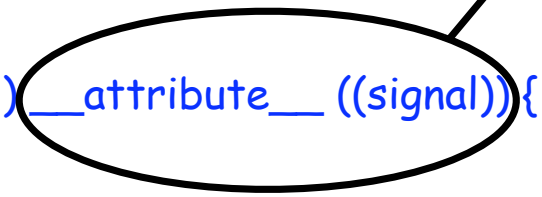
Installing ISRs

```
#include <avr/interrupt.h>
...
ISR (interrupt_name) {
    ... code ...
}
```

avr-gcc specific, may look very different on other platforms (if supported at all)

expands to

```
void _vector_x (void) __attribute__ ((signal)) {
    ... code ...
}
```



Preventing interrupts

```
cli();
... code that must not be interrupted ...
sei();
```

avr-gcc specific – may look very different on other platforms
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What's next?

- Timer-based yields (by means of an interrupt handler)
- Mutual exclusion (implementing lock and unlock)
- Generic interrupt- and event-handling (lab 3)

- ... all the bells and whistles of a real os! (optional :-)

- Time to jump into lab 2!