How does deoptimization help us go faster?

And other questions you were sensible enough not to ask!

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An exploration of why making Perl 6 fast is hard, and some of the techniques and computer science we're throwing at the problem

The Challenge

Let's write Perl 6 in Perl 6!

Ambitious language with lots of powerful abstractions and late binding

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Let's write Perl 6 in Perl 6!

A language we hadn't implemented yet, let alone made fast

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...which does a method call @a.AT-POS...

Indexing an array (@a[$x])

A multiple dispatch to the sub postcircumfix:<[ ]> (with candidates for one index, slicing, code (e.g. @a[*-1])...

...which does a method call @a.AT-POS...

...which gets the element and returns it if it already exists, or sets up a Scalar with an auto-vivification callback if not

Loop over the lines in a file

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Get an iterator and call .pull-one on it...

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...which calls .consume-line-chars on the decoder (pluggable userspace encodings) and, if it fails, get bytes to refill the buffer...

Loop over the lines in a file

Get an iterator and call .pull-one on it...

...which calls .consume-line-chars on the decoder (pluggable userspace encodings!) and, if it fails, get bytes to refill the buffer...

...and then call the block of the loop, passing the line as an argument to it

All these darn calls

In a language where...

Method resolution is pluggable
Type checking is pluggable
We have continuation-powerful constructs
Stack frames are first class
A mixin can change an object's type
Frames can have exit handlers (LEAVE etc.)

Rakudo Perl 6 Compiler Architecture

Perl 6 Source

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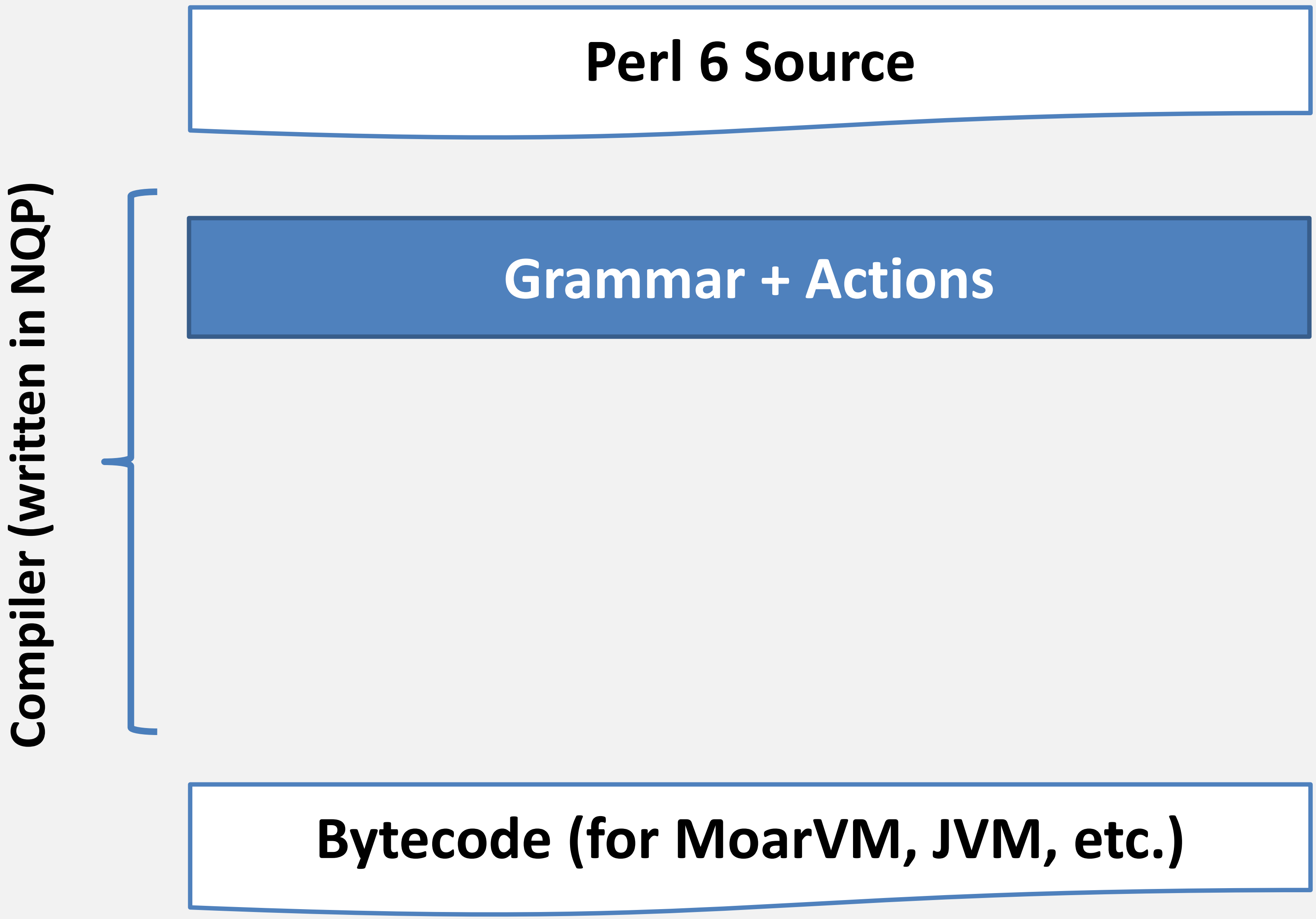
Bytecode (for MoarVM, JVM, etc.)

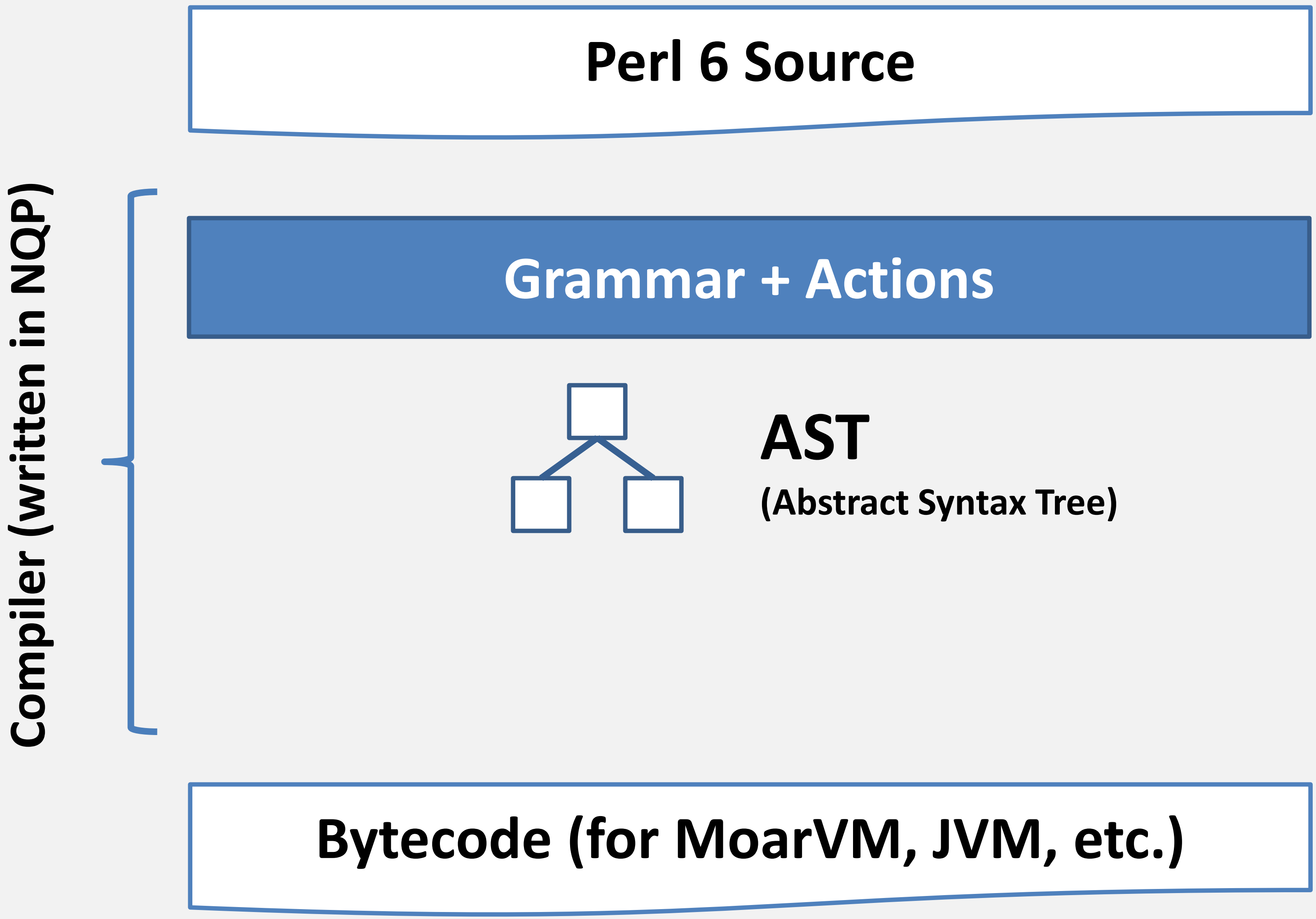
Perl 6 Source

Compiler (written in NQP)

Bytecode (for MoarVM, JVM, etc.)



Perl 6 Source
Compiler (written in NQP)
Grammar + Actions
Bytecode (for MoarVM, JVM, etc.)


Perl 6 Source
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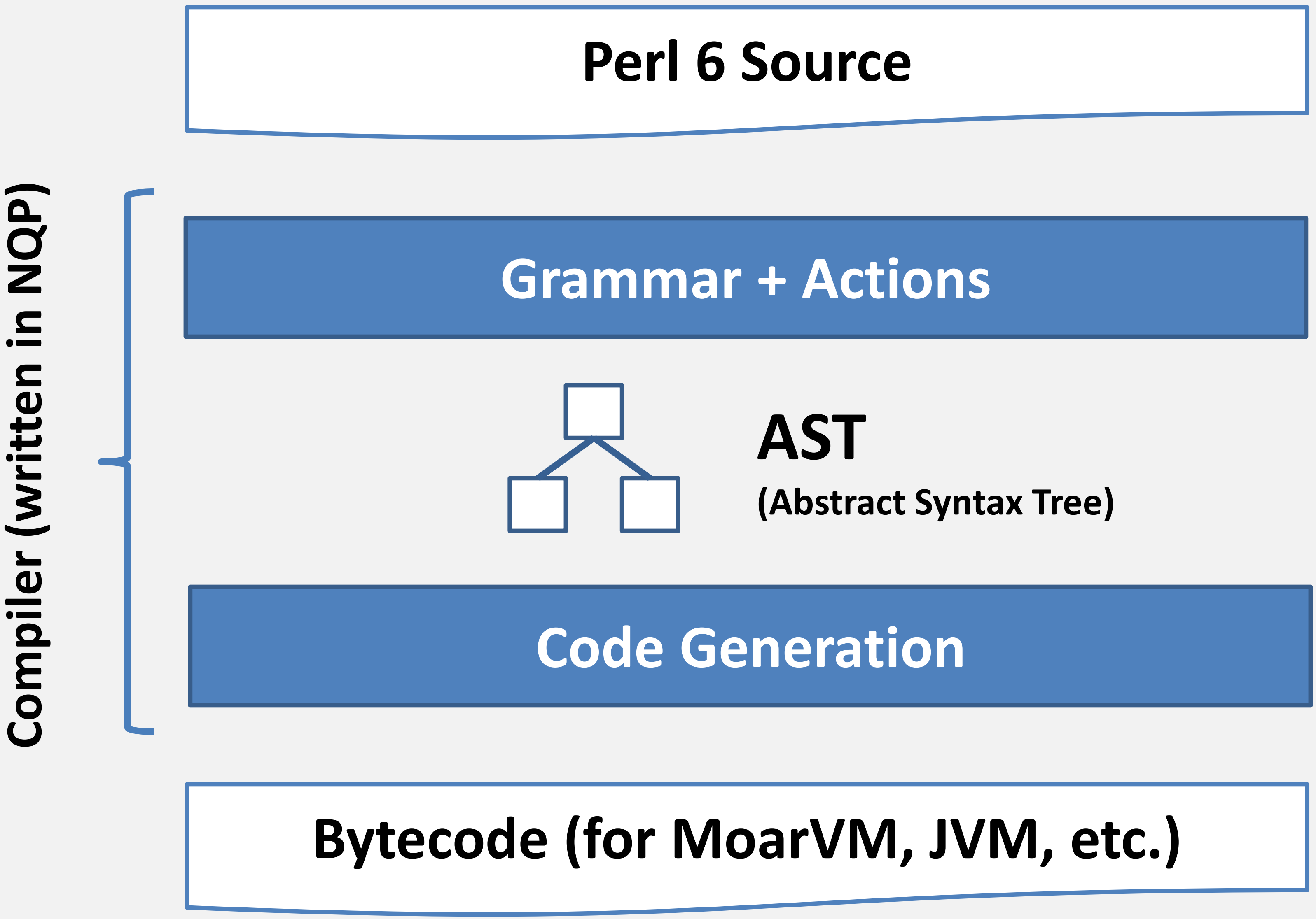


Perl 6 Source
Compiler (written in NQP)
Grammar + Actions
AST
(Abstract Syntax Tree)
Code Generation
Bytecode (for MoarVM, JVM, etc.)

Compiler is a Perl 6 program, running on the same VM instance (and thus in the same process) as the program it compiles

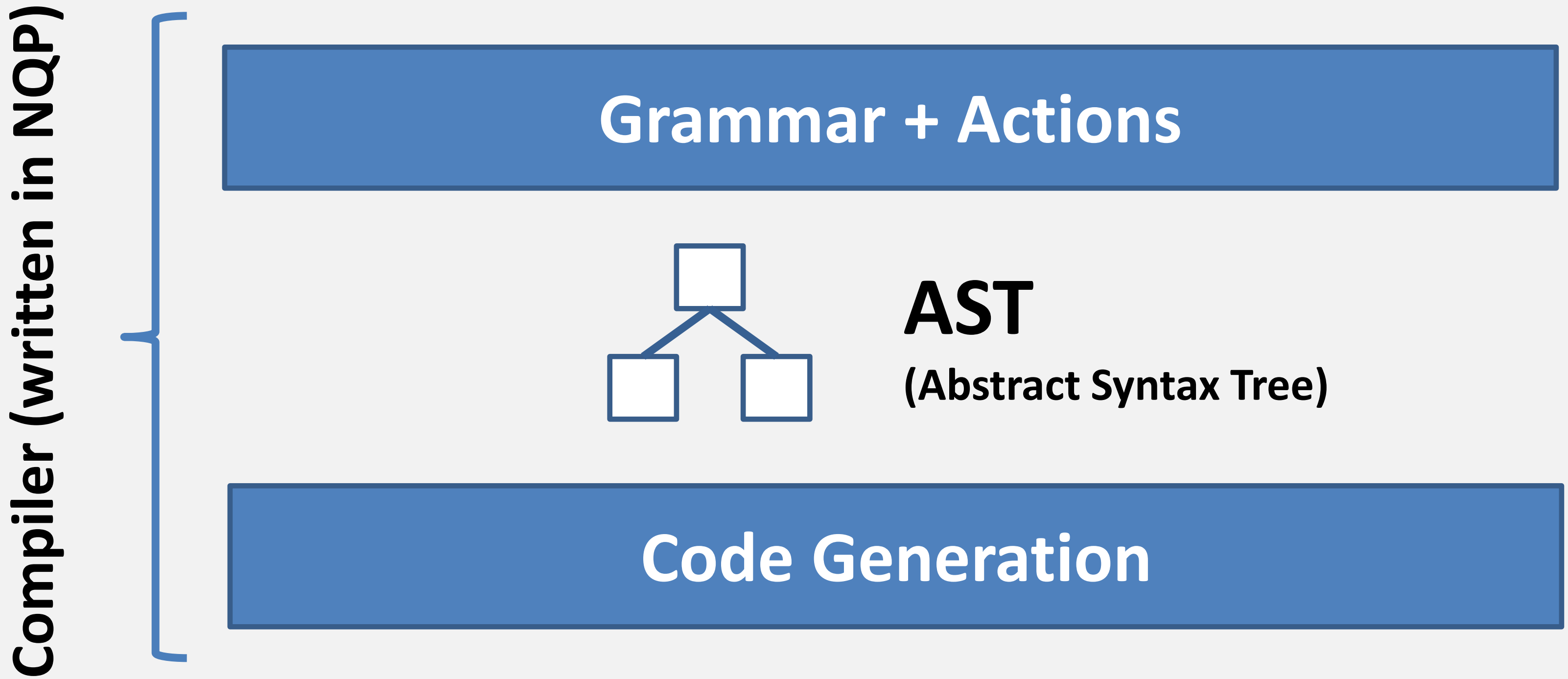
Scripts/one-liners: bytecode in memory

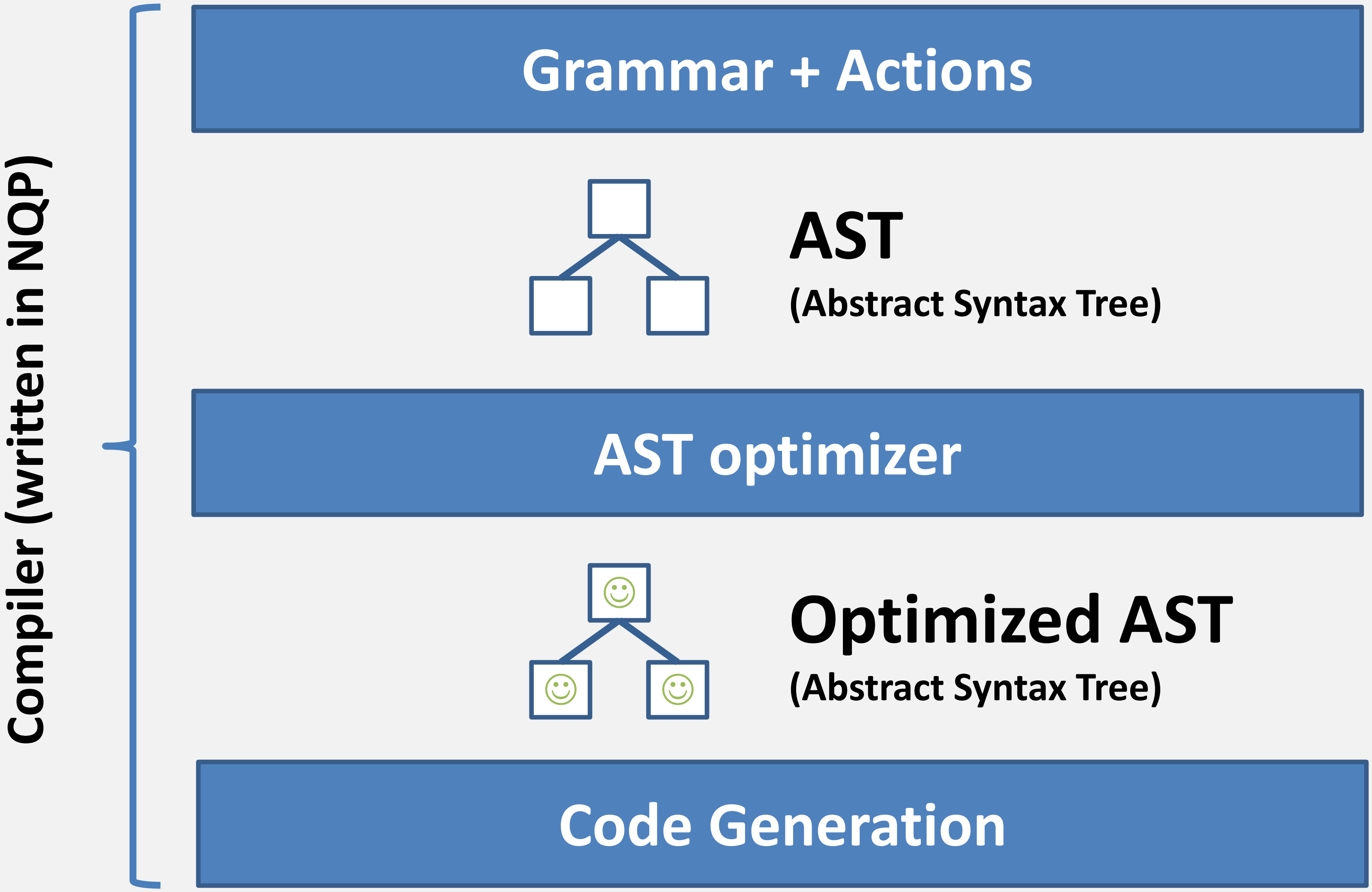
Modules: cache bytecode on disk (sounds easy; actually hard to have it Just Work)

EVAL - just a call into the compiler (also means bytecode has to be possible to GC)

Program Optimization

Actually, this wasn't the whole truth...




Compiler (written in NQP)
Grammar + Actions
AST
(Abstract Syntax Tree)
AST optimizer
Optimized AST
(Abstract Syntax Tree)
Code Generation

AST optimizer

Constant folding (calls to `is PURE` subs)

(Some) lexical to local lowering, plus flattening scopes where it won't matter

Inlining of native int/num/str operators

Assorted rewrites to constructs into cheaper equivalents that do the same

It has been said:

"Don't put off until runtime that which you could do at compile time"

But:

For scripts and one-liners, the language user doesn't experience compile time and runtime, just time

And also:

When we compile a module, we know little about its usage patterns; they may vary wildly between different programs

How many compile times?

We aren't limited to just one

Just In Time compilers give us another round of compilation

So, I'd argue:

Only do in *this* compile time something that a later compile time couldn't do better and/or more simply

Known Unknowns

Even this simple module is packed with unknowns…

```
sub average-line-chars($handle) is export {
    my $total-chars = 0;
    my $total-lines = 0;
    for $handle.lines -> $line {
        $total-chars += $line.chars;
        $total-lines++;
    }
    return $total-chars / $total-lines;
}
```

We don't know the types of the parameters

```
sub average-line-chars($handle) is export {
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    }
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}
```

We don’t know the types of method invocants

```
sub average-line-chars($handle) is export {
    my $total-chars = 0;
    my $total-lines = 0;
    for $handle.lines -> $line {
        $total-chars += $line.chars;
        $total-lines++;
    }
    return $total-chars / $total-lines;
}
```

We don’t know the types of arguments to operators

```
sub average-line-chars($handle) is export {
    my $total-chars = 0;
    my $total-lines = 0;
    for $handle.lines -> $line {
        $total-chars += $line.chars;
        $total-lines++;
    }
    return $total-chars / $total-lines;
}
```

Even if we had type annotations, we could be passed a subtype (except for native types)

Anything we pass as an argument may get mixed into

If we get passed a closure, we don't know what code is going to be invoked

In a given use of a module, it might turn out to be the same every time

We don't know if this loop will be hot or not

```
sub average-line-chars($handle) is export {
    my $total-chars = 0;
    my $total-lines = 0;
    for $handle.lines -> $line {
        $total-chars += $line.chars;
        $total-lines++;
    }
    return $total-chars / $total-lines;
}
```

In summary…

We don't know what to spend effort optimizing

We don’t know what cases to optimize it for

Dynamic problem? Dynamic solution!

Interpreter logging

Initially, run bytecode using an interpreter

Have various instructions log encountered types, code, etc.

Can logging be cheap enough?

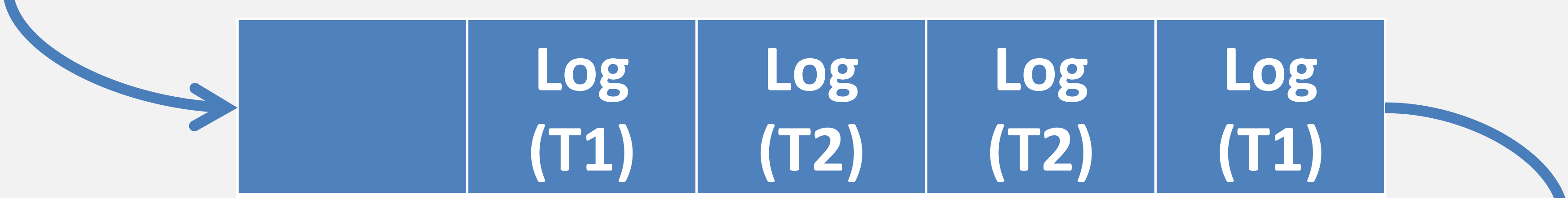
Append 24-byte entries into a buffer until it is full

Entries carry a call frame ID to allow stack reconstruction

Optimization thread

Receives filled buffers

Threads place full log buffers
into a concurrent queue



Optimization worker thread
removes them one at a time

Aggregation

Replay the recorded events on a simulated call stack

Gradually build up statistics about types, callees, etc.

Example program

```
my $fh = open "longfile";
my $chars = 0;
for $fh.lines {
    $chars = $chars + .chars
}
$fh.close;
say $chars
```

Example program

```
my $fh = open "longfile";
my $chars = 0;
for $fh.lines {
    $chars = $chars + .chars
}
$fh.close;
say $chars
```

Calls pull-one on iterator to get each line

```
method pull-one() {
    # Slow path falls back to .get on the
    # handle, which will replenish the buffer.
    $!decoder.consume-line-chars(:$!chomp) //
        ($!handle.get // IterationEnd)
}
```

Statistics for chars method

```
Latest statistics for 'chars' (cuid: 4208, file:
SETTING::src/core/Str.pm:2728)

Total hits: 468

Callsite 0x7f0b7089da60 (1 args, 1 pos)
Positional flags: obj

    Callsite hits: 468

    Maximum stack depth: 13

    Type tuple 0
        Type 0: Str (Conc)
        Hits: 468
        Maximum stack depth: 13
```

Statistics for infix:<+>

```
Latest statistics for 'infix:<+>' (cuid: 3129, file:
SETTING::src/core/Int.pm:245)

Total hits: 469

Callsite 0x7f0b7089da40 (2 args, 2 pos)
Positional flags: obj, obj

    Callsite hits: 469

    Maximum stack depth: 35

    Type tuple 0
        Type 0: RW Scalar (Conc) of Int (Conc)
        Type 1: Int (Conc)
        Hits: 469
        Maximum stack depth: 35
```

Statistics for read-internal

```
Latest statistics for 'read-internal' (cuid: 9529, file:
SETTING::src/core/IO/Handle.pm:220)

Total hits: 1

Callsite 0x7f0b7089da40 (2 args, 2 pos)
Positional flags: obj, obj

    Callsite hits: 1

    Maximum stack depth: 16

    Type tuple 0
        Type 0: IO::Handle (Conc)
        Type 1: Int (Conc)
        Hits: 1
        Maximum stack depth: 16
```

Not hot, won't optimize (yet)

Statistics for defined (1)

```
Latest statistics for 'defined' (cuid: 356, file:
SETTING::src/core/Mu.pm:106)

Total hits: 475
```

Hot, but...

```
Callsite 0x7f0b7089da60 (1 args, 1 pos)
Positional flags: obj

    Callsite hits: 475

    Maximum stack depth: 32

    Type tuple 0
        Type 0: Scalar (Conc) of Any (TypeObj)
        Hits: 1
        Maximum stack depth: 26
```

Not on a Scalar holding Any...

...

Statistics for defined (2)

…

```
Type tuple 4
       Type 0: Str (TypeObj)
       Hits: 2
       Maximum stack depth: 14

   Type tuple 5
       Type 0: Int (Conc)
       Hits: 1
       Maximum stack depth: 32

   Type tuple 6
       Type 0: Str (Conc)
       Hits: 468
       Maximum stack depth: 13
```

Nor on a Str type object…

Nor on an Int

But LOADS of calls on a Str!

Statistics for loop body (1)

```
Latest statistics for '' (cuid: 1, file: -e:3)

Total hits: 468

Callsite 0x7f0b7089da60 (1 args, 1 pos)
Positional flags: obj

    Callsite hits: 468

    Maximum stack depth: 12

    Type tuple 0
        Type 0: Str (Conc)
        Hits: 468
        Maximum stack depth: 12
...
```

Always given a Str

Statistics for loop body (2)

```
Logged at offset:
    68:
        468 x type Scalar (Conc)
    76:
        468 x type Str (Conc)
    110:
        468 x type Int (Conc)
        468 x static frame 'chars' (4208)
        468 x type tuple:
            Type 0: Str (Conc)
    144:
        468 x type Int (Conc)
        468 x static frame 'infix:<+>' (3129)
        468 x type tuple:
            Type 0: RW Scalar (Conc) of Int (Conc)
            Type 1: Int (Conc)
```

Always same chars method, always Str → Int

Planning

The statistics are used to plan what code to optimize, and what cases to optimize it for

Planning: what's hot?

The total number of calls to a given block or routine provides an indication of whether to consider it further; it's weighed up against bytecode size

*morphic

We can classify a callsite, or the overall use of a routine, as monomorphic, polymorphic, and megamorphic

Monomorphic

Only a single type (or tuple of types) is observed (or the outliers are so few we might as well consider it so)

Polymorphic

A few different types (or tuples of types) are observed (again, we're willing to overlook the odd outlier)

Megamorphic

Many different types show up without any being notably more common

Plan for infix:<+>

```
Observed type specialization of 'infix:<+>' (cuid: 3129,
file: SETTING::src/core/Int.pm:245)

The specialization is for the callsite:
Callsite 0x7f0b7089da40 (2 args, 2 pos)
Positional flags: obj, obj

It was planned for the type tuple:
    Type 0: RW Scalar (Conc) of Int (Conc)
    Type 1: Int (Conc)
Which received 469 hits (100% of the 469 callsite hits).

The maximum stack depth is 35.
```

Totally monomorphic

Plan for method Mu.defined

```
Observed type specialization of 'defined' (cuid: 356,
file: SETTING::src/core/Mu.pm:106)

The specialization is for the callsite:
Callsite 0x7f0b7089da60 (1 args, 1 pos)
Positional flags: obj

It was planned for the type tuple:
    Type 0: Str (Conc)
Which received 468 hits (98% of the 475 callsite hits).

The maximum stack depth is 13.
```

Monomorphic-ish

Monomorphic/polymorphic

Can generate versions of the code specialized by input type

Will be one or just a few of them; worth the work/RAM

Megamorphic

Not worth producing type specializations

But can still do some other optimizations

In the future…

We'll analyze when a megamorphic sub/method is monomorphic/polymorphic in some arguments (this shows up in array/hash assignments)

Specialization Graph

So, we've decided what we're going to optimize and, typically, what types we'll produce specializations for

What next?

We need to turn the bytecode into a form that's ideal for analysis and transformation

Basic blocks

Sequences of instructions that do not involve flow control (such as a branch or an exception throw) or invocation (calling things)

Basic blocks and Perl 6

A lot of operations are what we've called invokish - they *may* lead to a function call

(For example, decont of a `Scalar` won't, but of a `Proxy` will)

```
checkarity      liti16(1), liti16(1)
param_rp_o        r1, liti16(0)
decont            r8,   r1

wval              r9, liti16(1), liti16(35) (P6opaque: Str)
istype           r10,   r8,   r9

assertparamcheck r10

decont            r9,   r1

set               r0,   r9
param_sn          r2
takedispatcher    r3
wval              r4, liti16(1), liti16(35) (P6opaque: Str)
getattr_s         r5,   r0,   r4, lits($!value), liti16(0)
chars             r6,   r5
p6box_i           r4,   r6
wval              r7, liti16(1), liti16(37) (P6opaque: Int)
…
```

```
checkarity        liti16(1), liti16(1)
param_rp_o          r1, liti16(0)
decont              r8,   r1

wval                r9, liti16(1), liti16(35) (P6opaque: Str)
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param_sn            r2
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wval                r4, liti16(1), liti16(35) (P6opaque: Str)
getattr_s           r5,   r0,   r4, lits($!value), liti16(0)
chars               r6,   r5
p6box_i             r4,   r6
wval                r7, liti16(1), liti16(37) (P6opaque: Int)
```

May invoke (Proxy?)

…

```
checkarity       liti16(1), liti16(1)
param_rp_o         r1, liti16(0)
decont             r8,   r1          May invoke (Proxy?)

wval               r9, liti16(1), liti16(35) (P6opaque: Str)
istype            r10,   r8,   r9    May invoke (subset?)

assertparamcheck r10

decont             r9,   r1

set                r0,   r9
param_sn           r2
takedispatcher     r3
wval               r4, liti16(1), liti16(35) (P6opaque: Str)
getattr_s          r5,   r0,   r4, lits($!value), liti16(0)
chars              r6,   r5
p6box_i            r4,   r6
wval               r7, liti16(1), liti16(37) (P6opaque: Int)
…
```

```
checkarity        liti16(1), liti16(1)
param_rp_o          r1, liti16(0)
decont              r8,   r1
```
May invoke (Proxy?)

```
wval                r9, liti16(1), liti16(35) (P6opaque: Str)
istype             r10,   r8,   r9
```
May invoke (subset?)

```
assertparamcheck r10
```
May call error generator

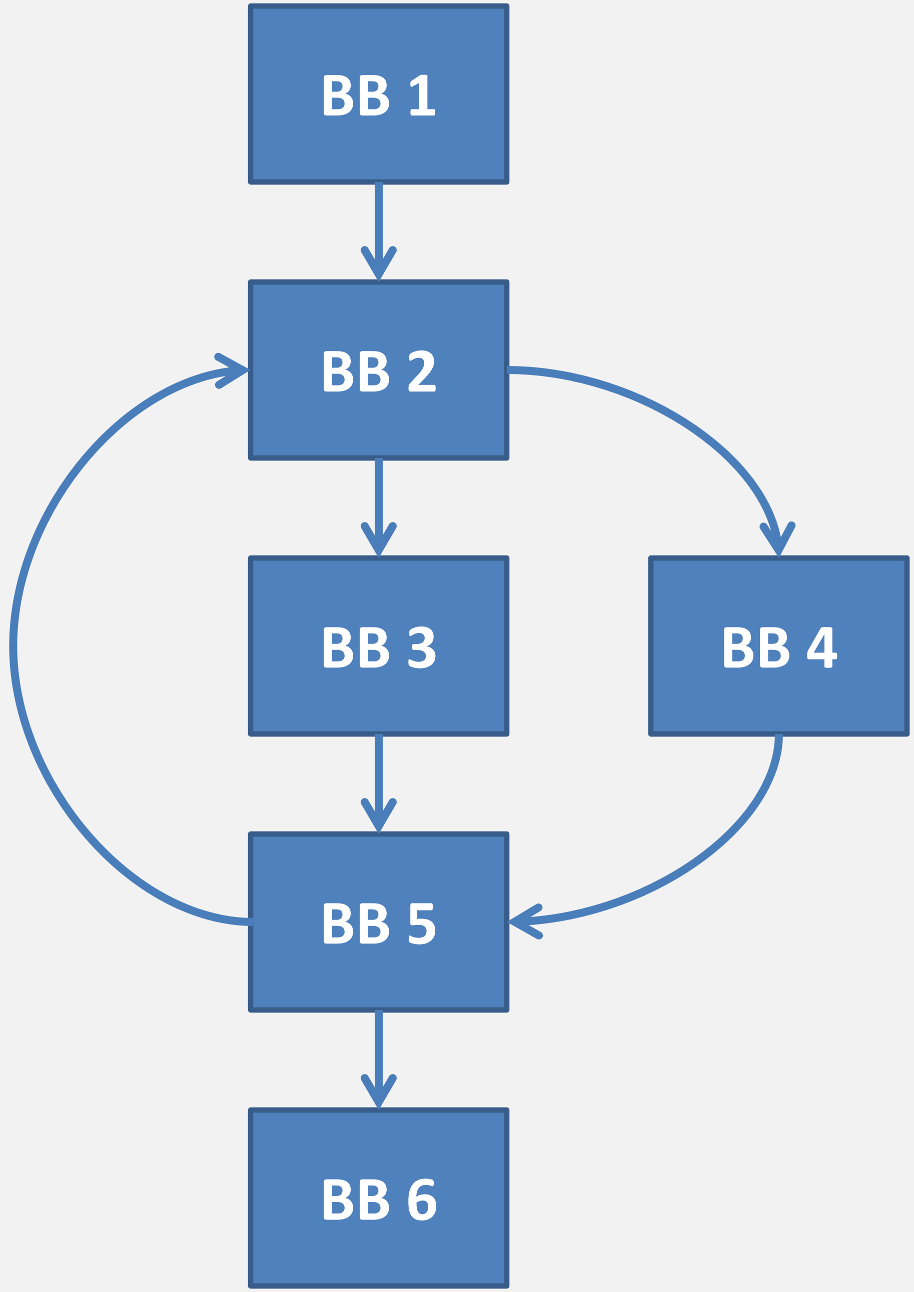
```
decont              r9,   r1

set                 r0,   r9
param_sn            r2
takedispatcher      r3
wval                r4, liti16(1), liti16(35) (P6opaque: Str)
getattr_s           r5,   r0,   r4, lits($!value), liti16(0)
chars               r6,   r5
p6box_i             r4,   r6
wval                r7, liti16(1), liti16(37) (P6opaque: Int)
…
```

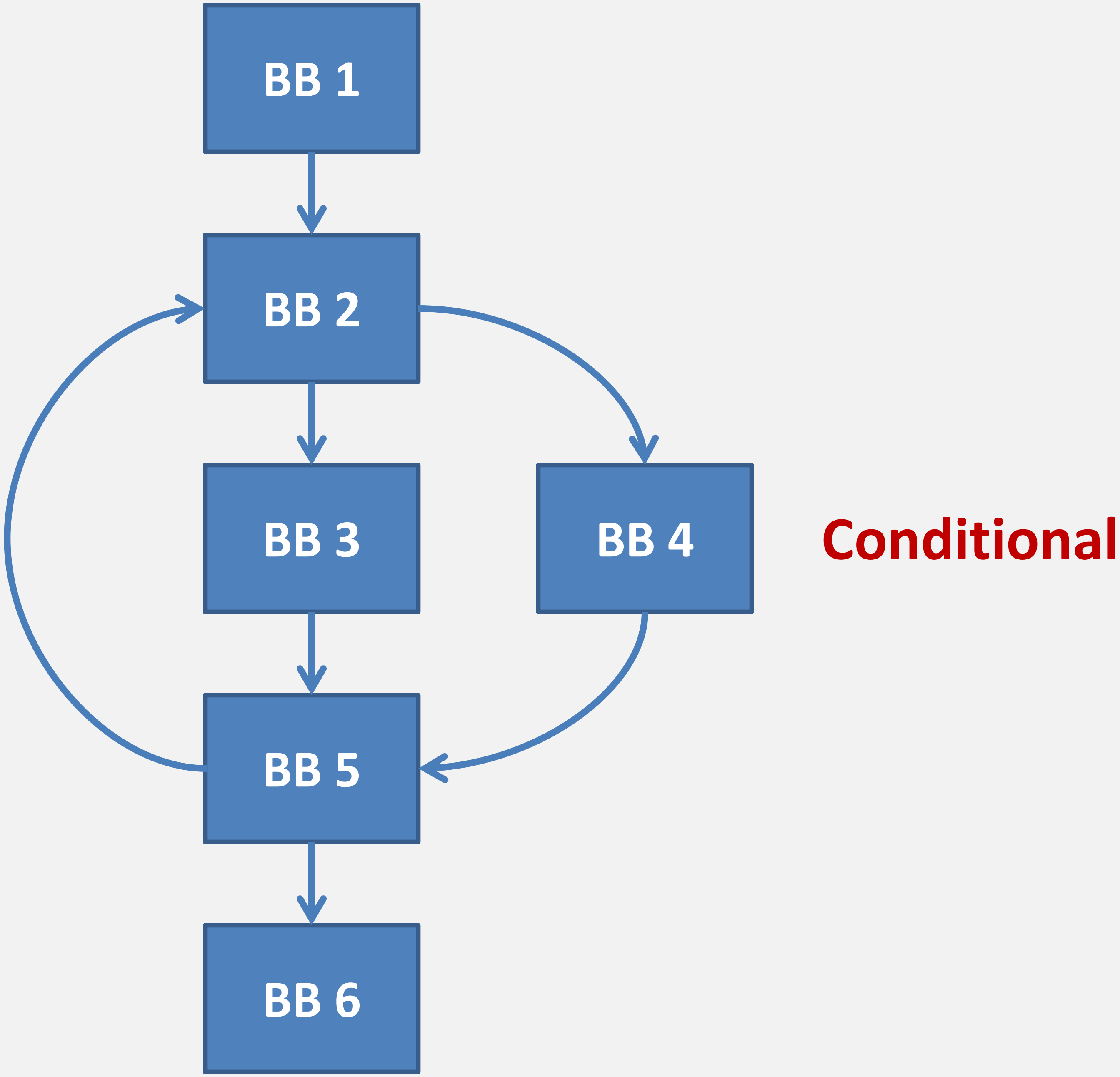
```
checkarity          liti16(1), liti16(1)
param_rp_o            r1, liti16(0)
decont                r8,    r1          May invoke (Proxy?)

wval                  r9, liti16(1), liti16(35) (P6opaque: Str)
istype               r10,    r8,    r9   May invoke (subset?)

assertparamcheck     r10                 May call error generator

decont                r9,    r1          May invoke (Proxy?)

set                   r0,    r9
param_sn              r2
takedispatcher        r3
wval                  r4, liti16(1), liti16(35) (P6opaque: Str)
getattr_s             r5,    r0,    r4, lits($!value), liti16(0)
chars                 r6,    r5
p6box_i               r4,    r6
wval                  r7, liti16(1), liti16(37) (P6opaque: Int)
…
```

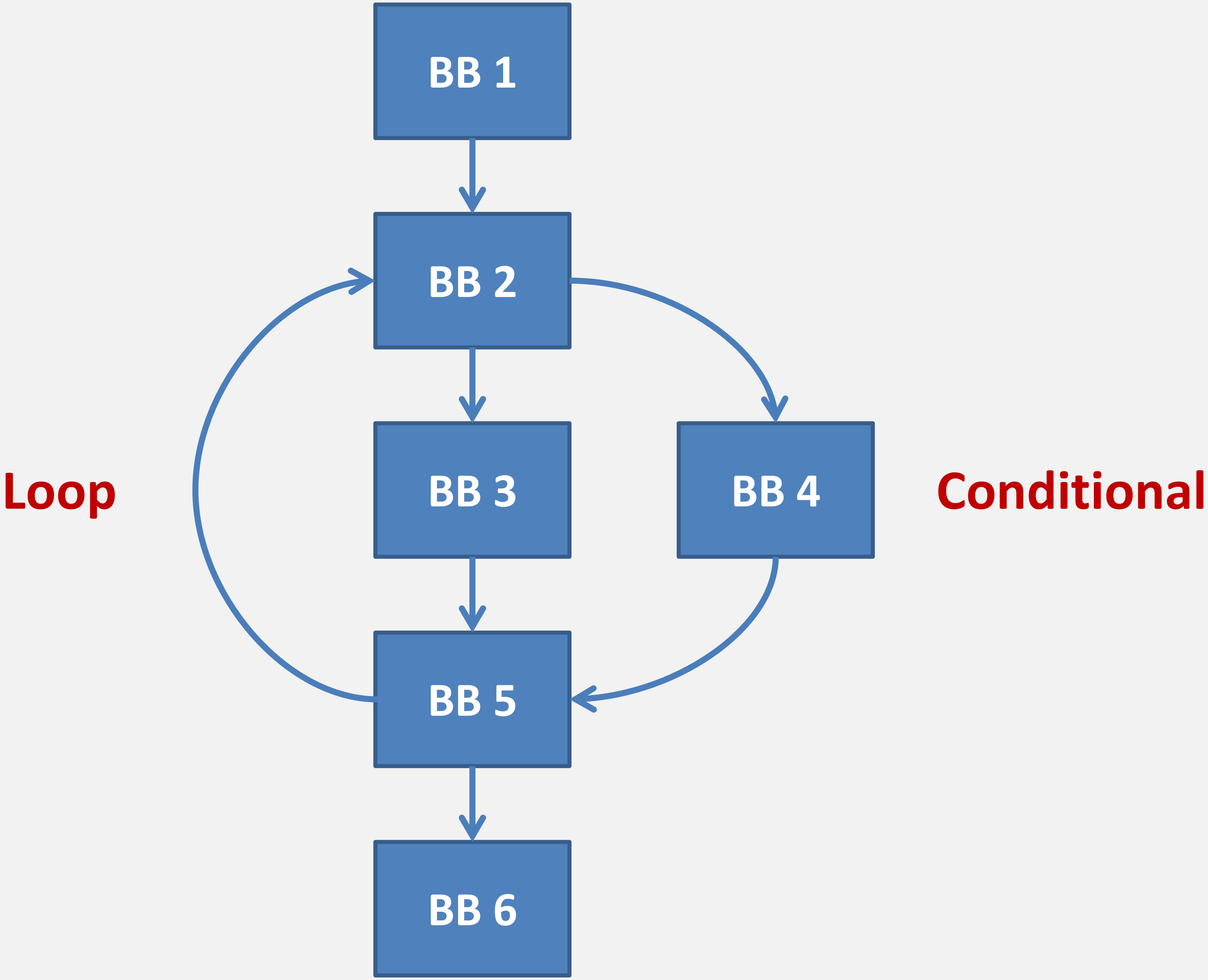
Control Flow Graph

Basic blocks are nodes

Put an edge when control may flow from one basic block to another


BB 1
BB 2
BB 3
BB 4
BB 5
BB 6


BB 1
BB 2
BB 3
BB 4
BB 5
BB 6
Conditional


BB 1
BB 2
BB 3
BB 4
BB 5
BB 6
Loop
Conditional

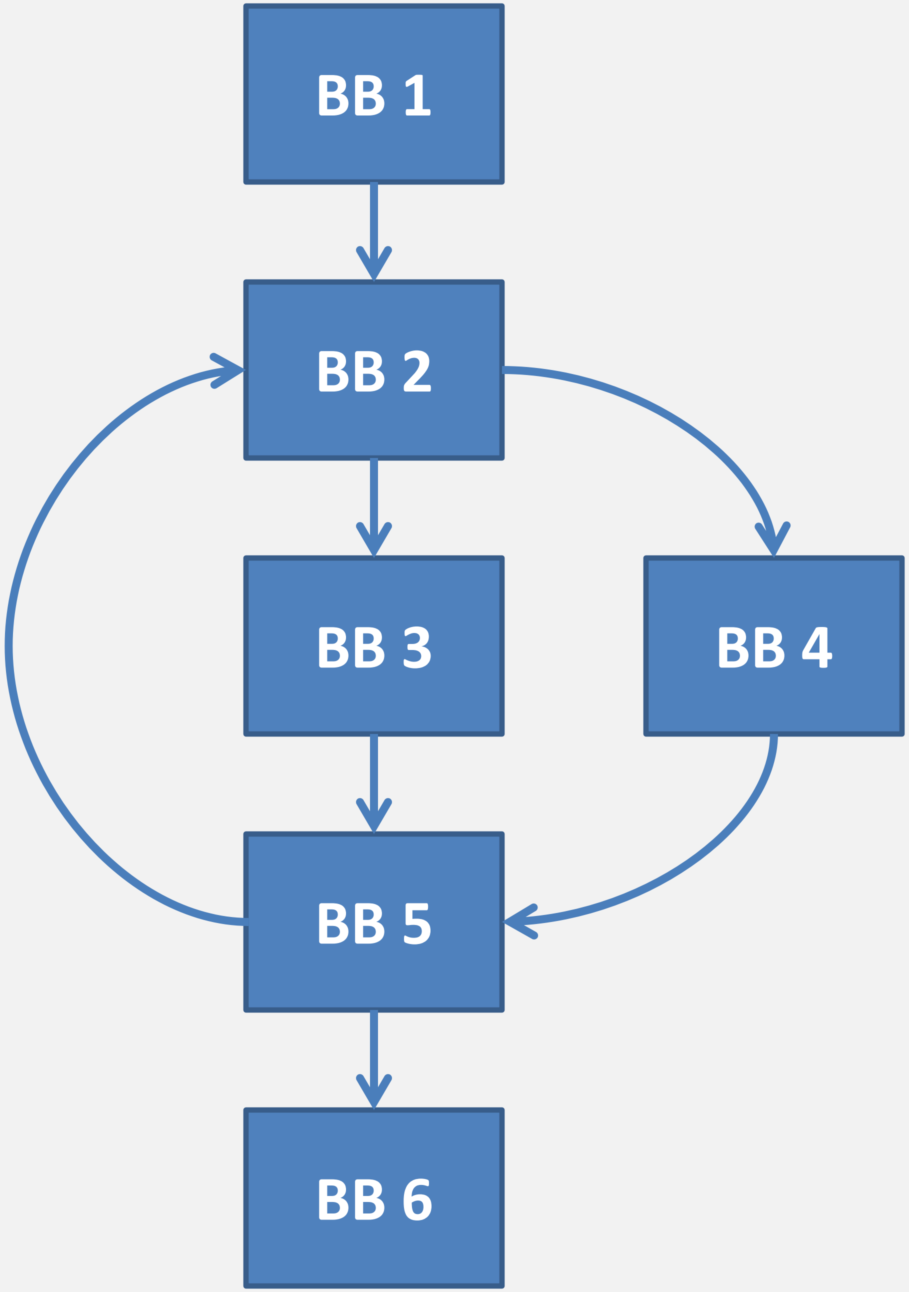
Successors and predecessors

The successors of a basic block are those we may go to

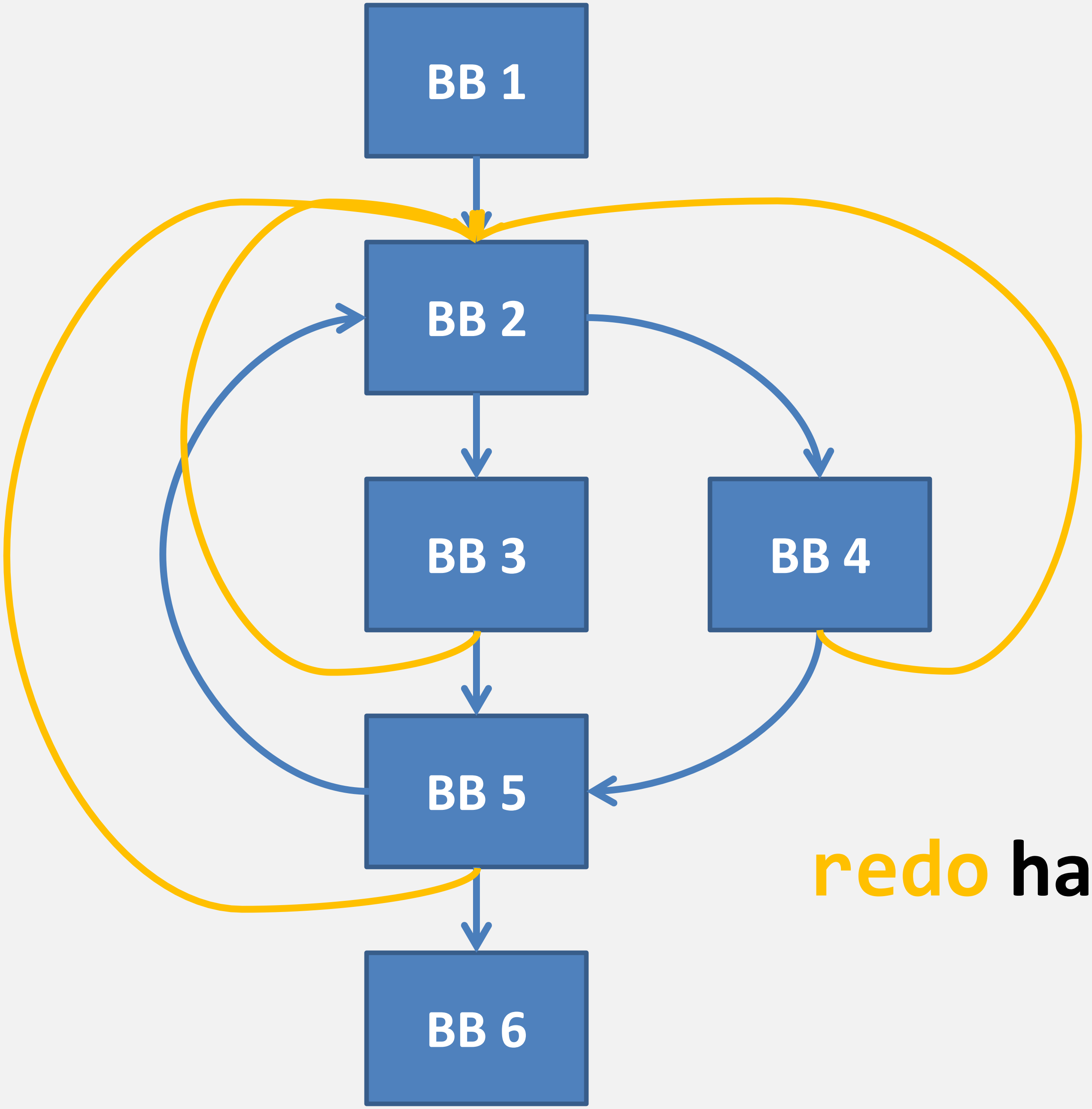
The predecessors of a basic block are those we may come from

Control exceptions

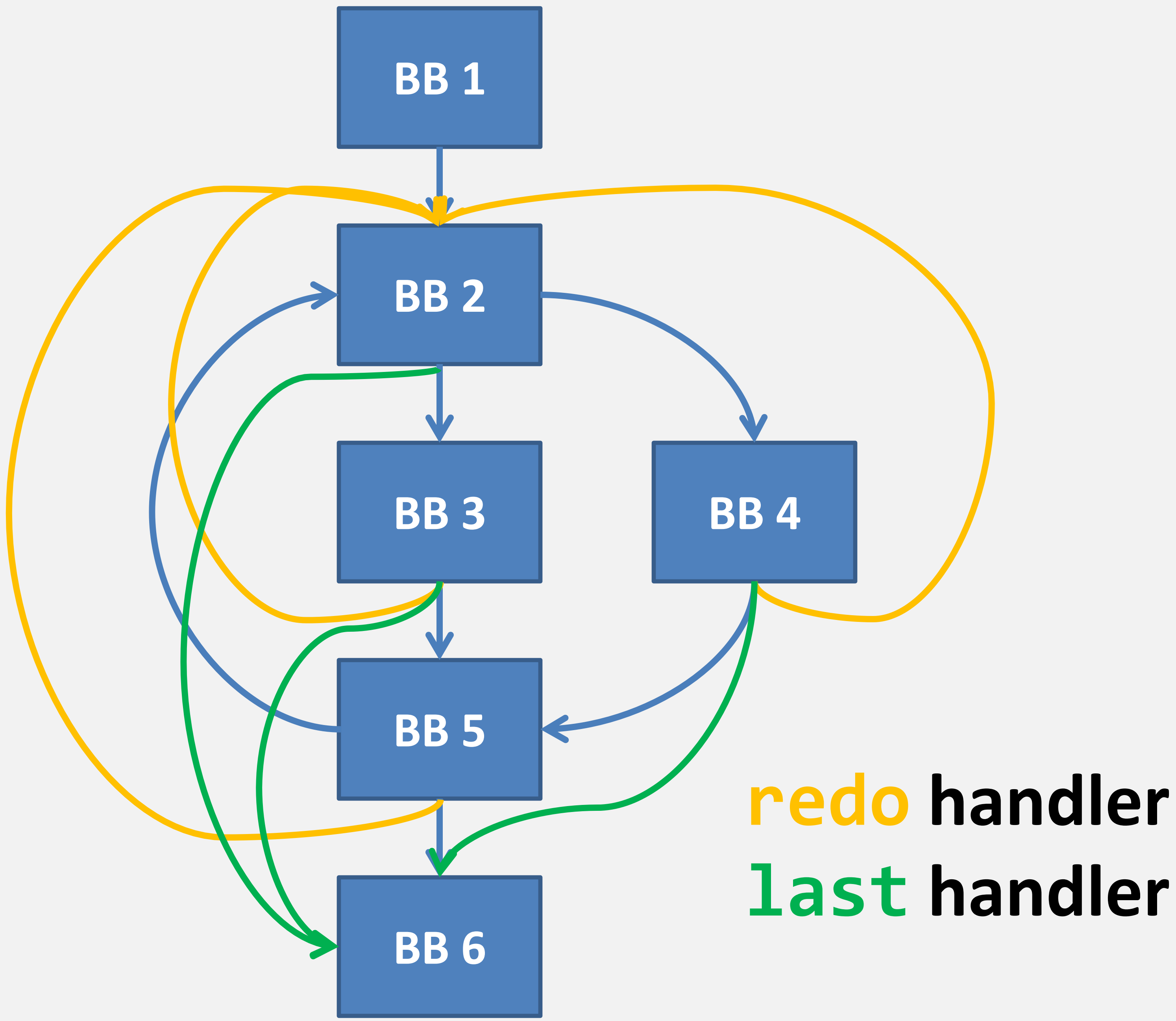
All basic blocks in the region covered by a control exception (`next`, `last`, etc.) are given the basic block of the handler as a successor



BB 1
BB 2
BB 3
BB 4
BB 5
BB 6



redo handler


BB 1
BB 2
BB 3
BB 4
BB 5
BB 6
redo handler
last handler

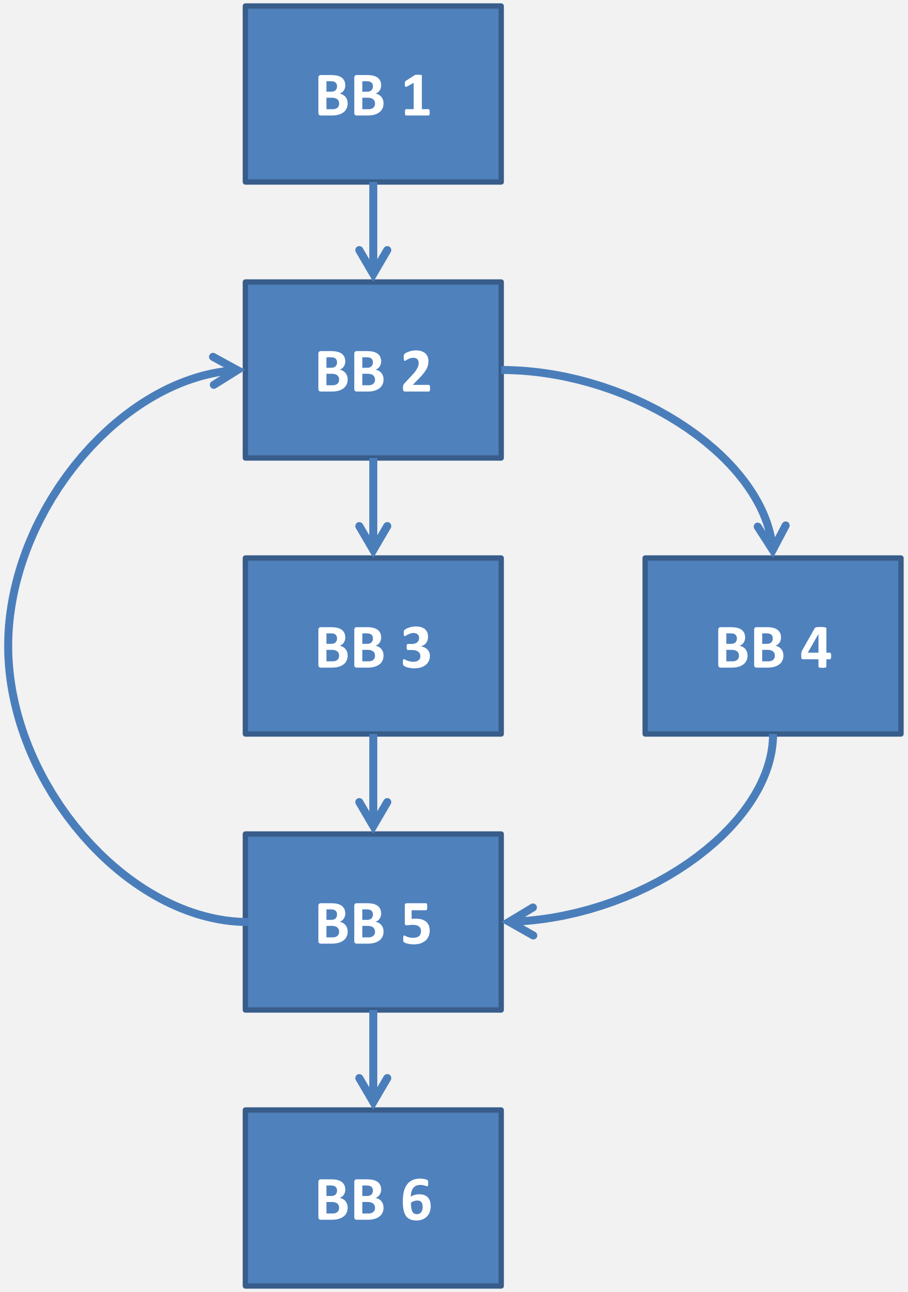
Non-control exceptions

For now, their handlers are all linked from an empty "entry point" basic block

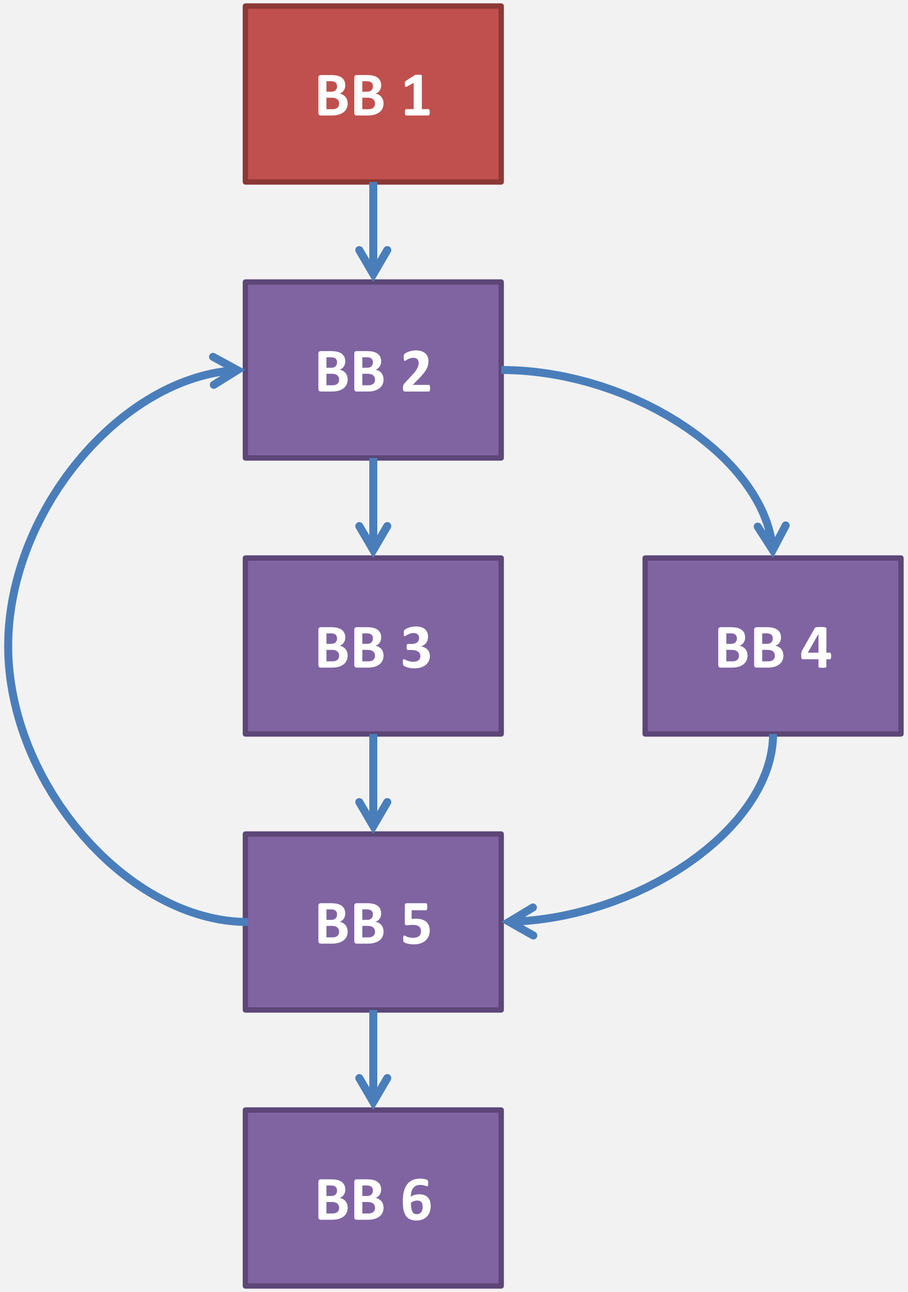
This is imprecise, but safe; we'll see why shortly…

Dominance

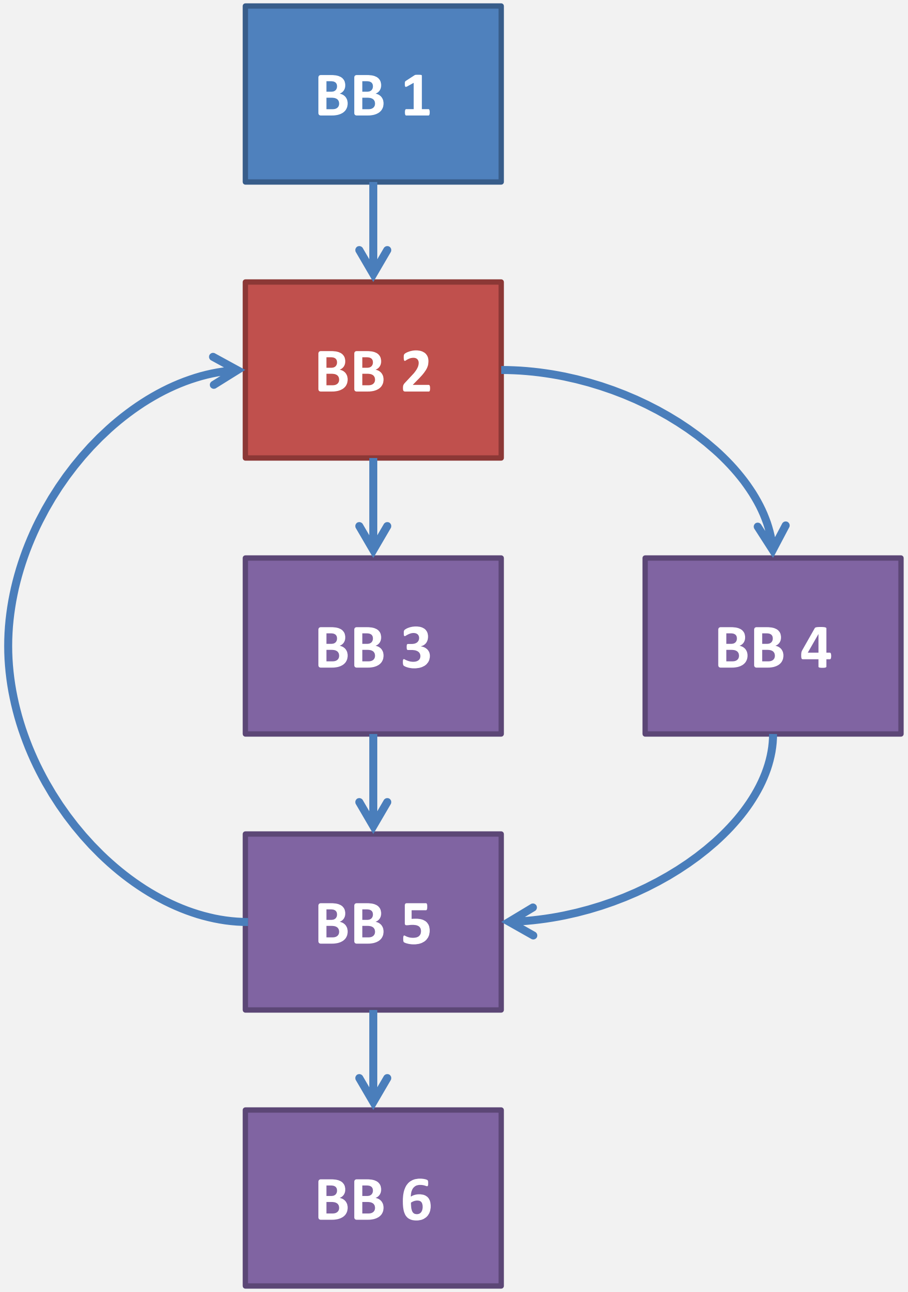
Basic block A <u>dominates</u> basic block B if every possible path through the CFG from the entry to B goes through A



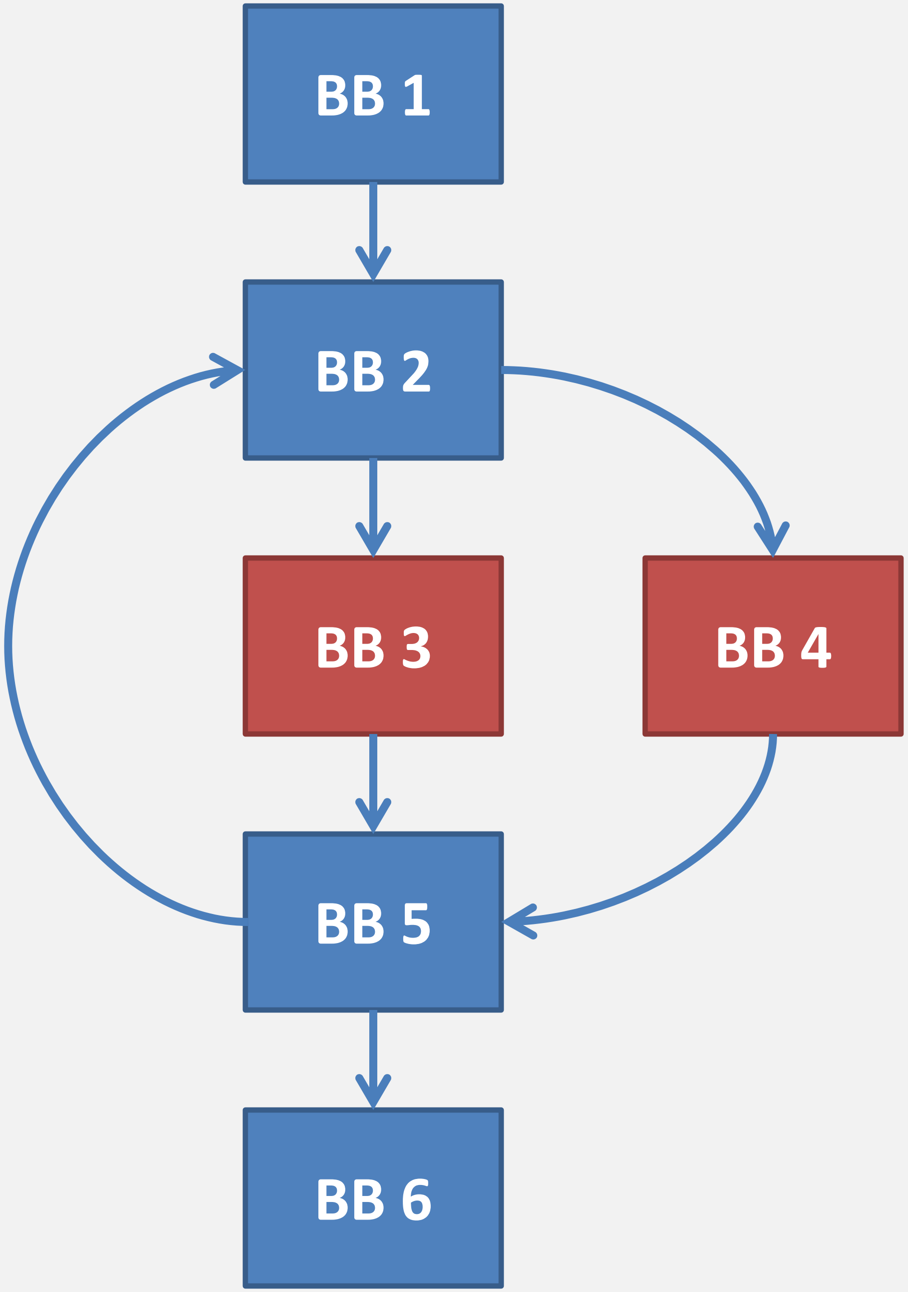
Block	Dominates



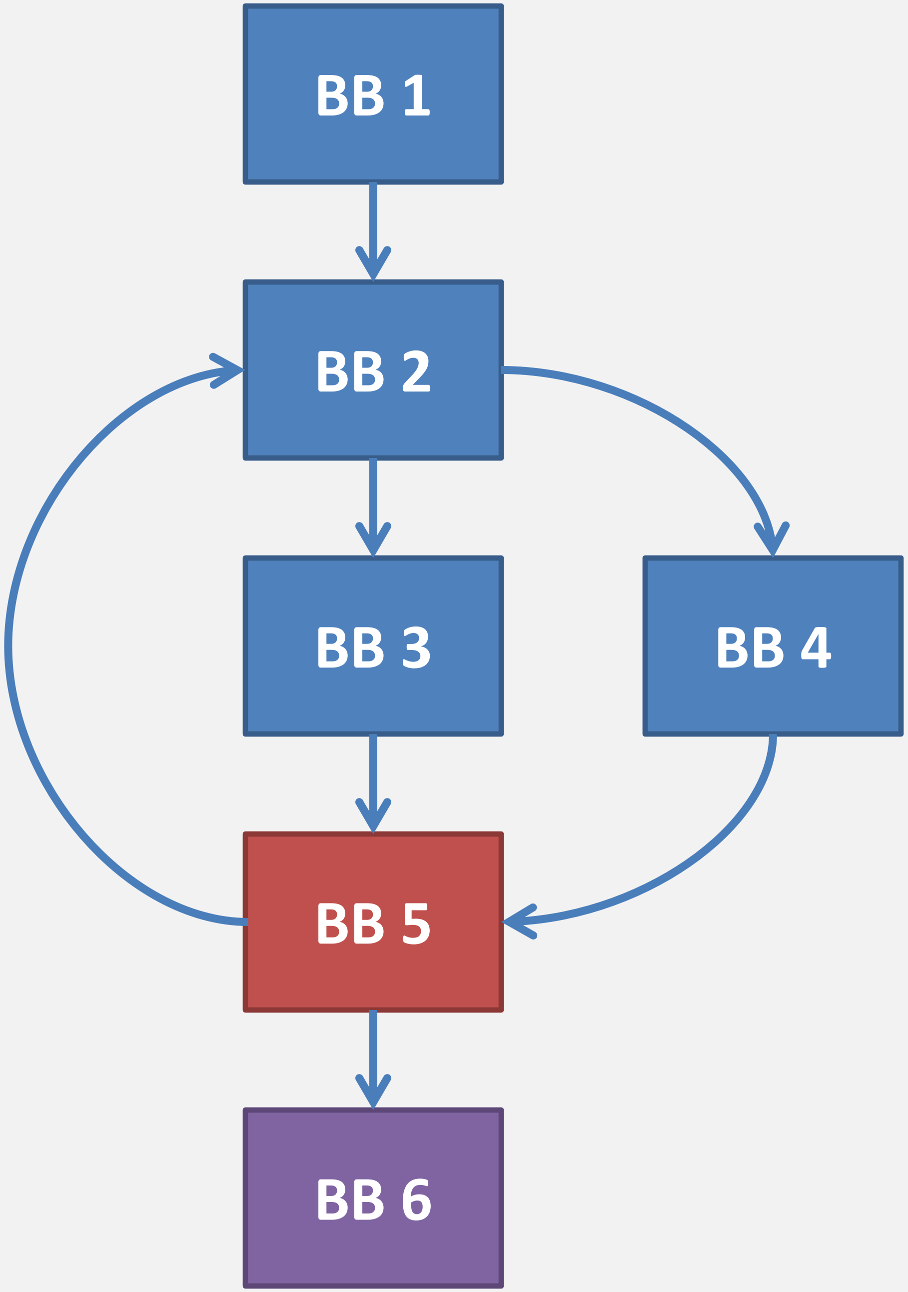
Block	Dominates
BB1	BB1, BB2, BB3, BB4, BB5, BB6



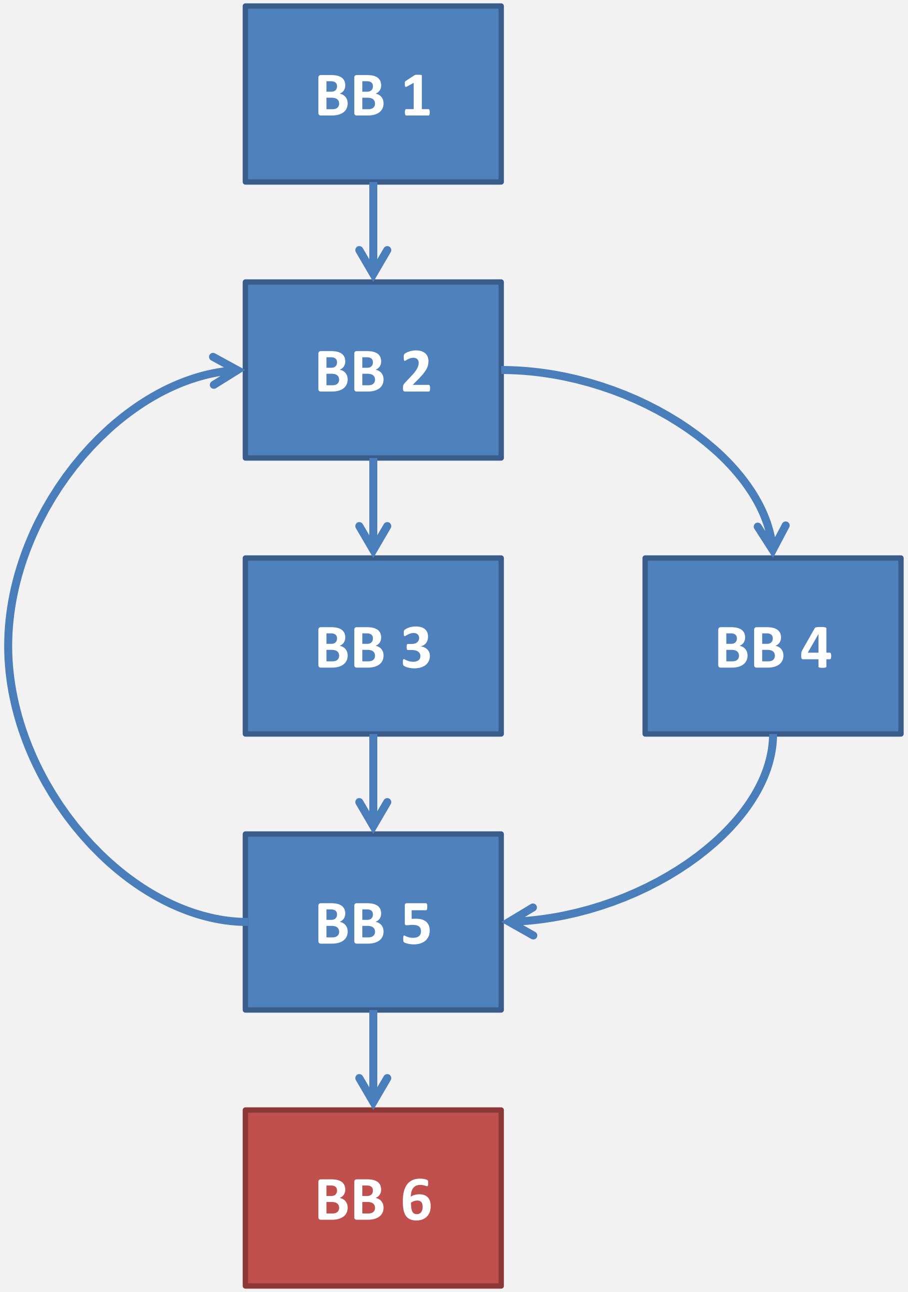
Block	Dominates
BB1	BB1, BB2, BB3, BB4, BB5, BB6
BB2	BB2, BB3, BB4, BB5, BB6



Block	Dominates
BB1	BB1, BB2, BB3, BB4, BB5, BB6
BB2	BB2, BB3, BB4, BB5, BB6
BB3	BB3
BB4	BB4



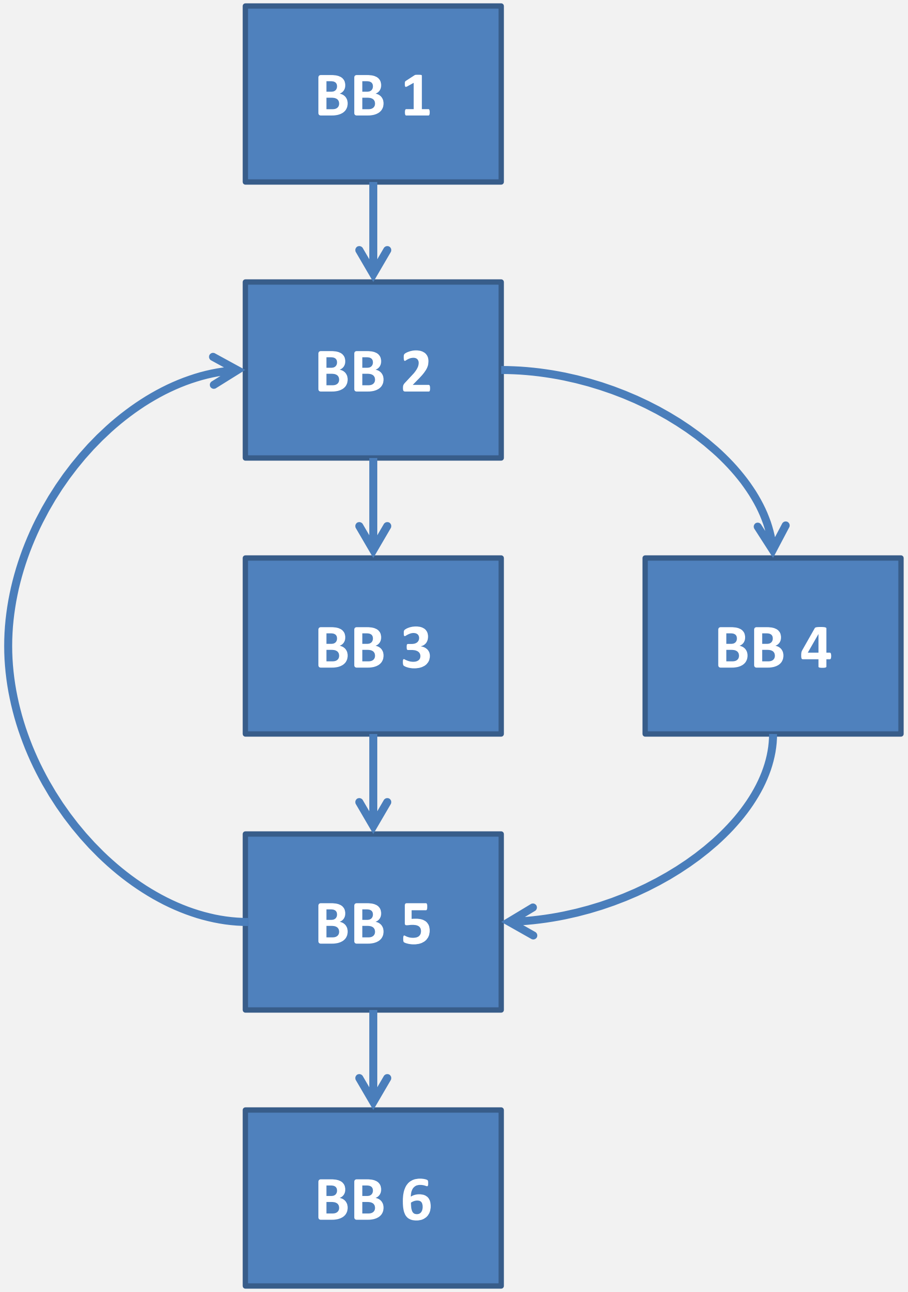
Block	Dominates
BB1	BB1, BB2, BB3, BB4, BB5, BB6
BB2	BB2, BB3, BB4, BB5, BB6
BB3	BB3
BB4	BB4
BB5	BB5, BB6



Block	Dominates
BB1	BB1, BB2, BB3, BB4, BB5, BB6
BB2	BB2, BB3, BB4, BB5, BB6
BB3	BB3
BB4	BB4
BB5	BB5, BB6
BB6	BB6

Strict dominance

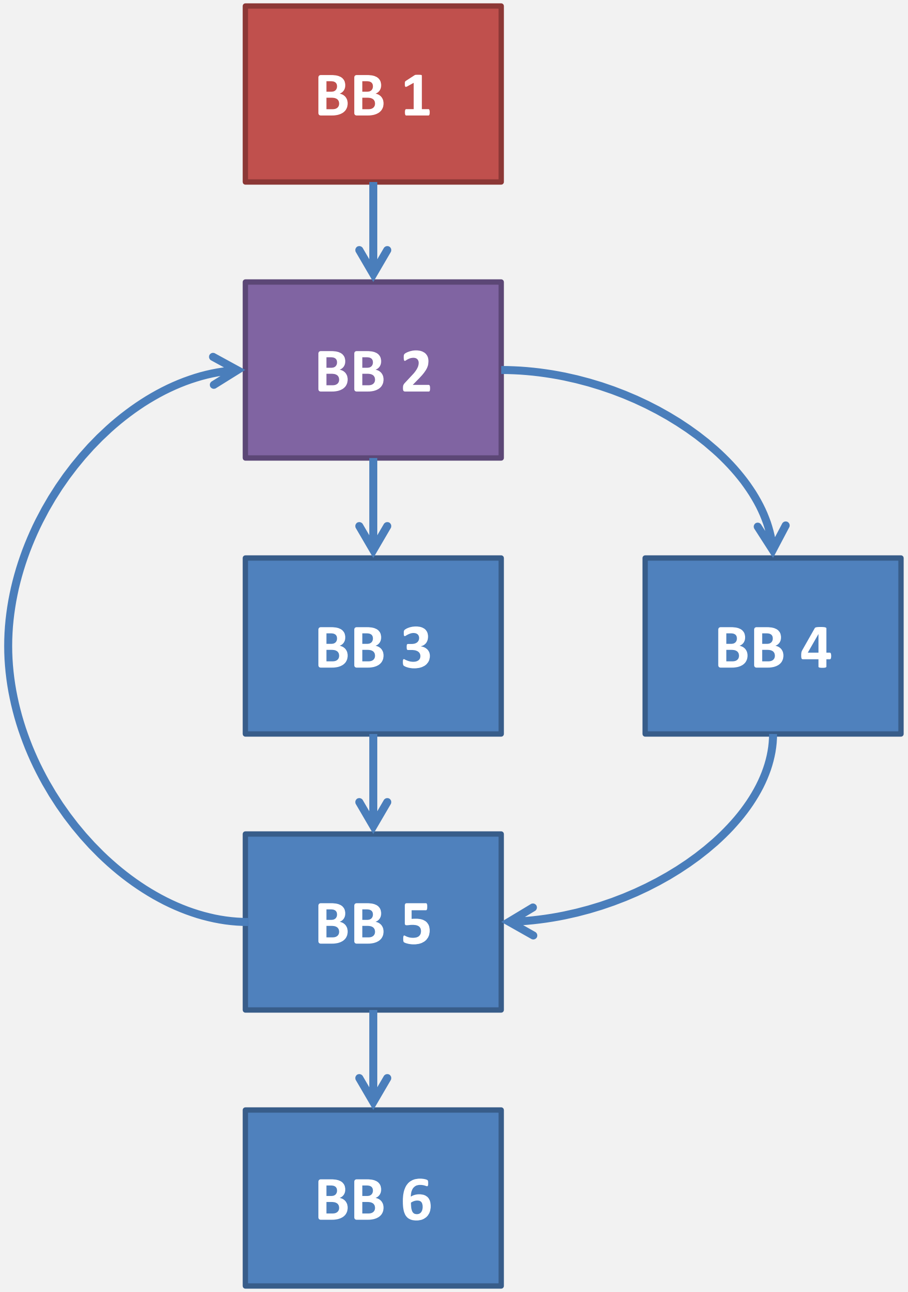
Just means excluding block's dominance of themselves



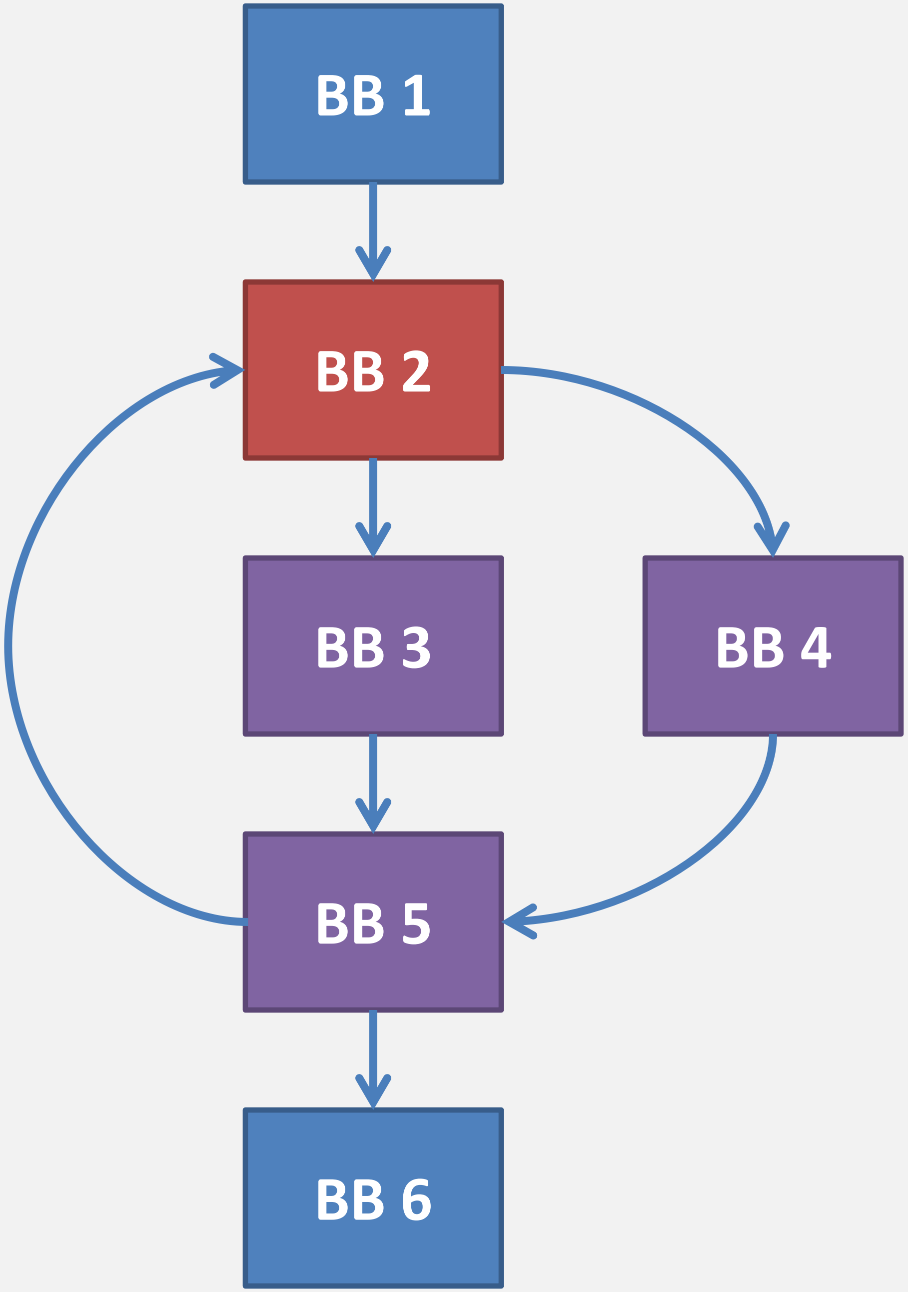
Block	Strictly Dominates
BB1	BB2, BB3, BB4, BB5, BB6
BB2	BB3, BB4, BB5, BB6
BB3	
BB4	
BB5	BB6
BB6	

Immediate dominance

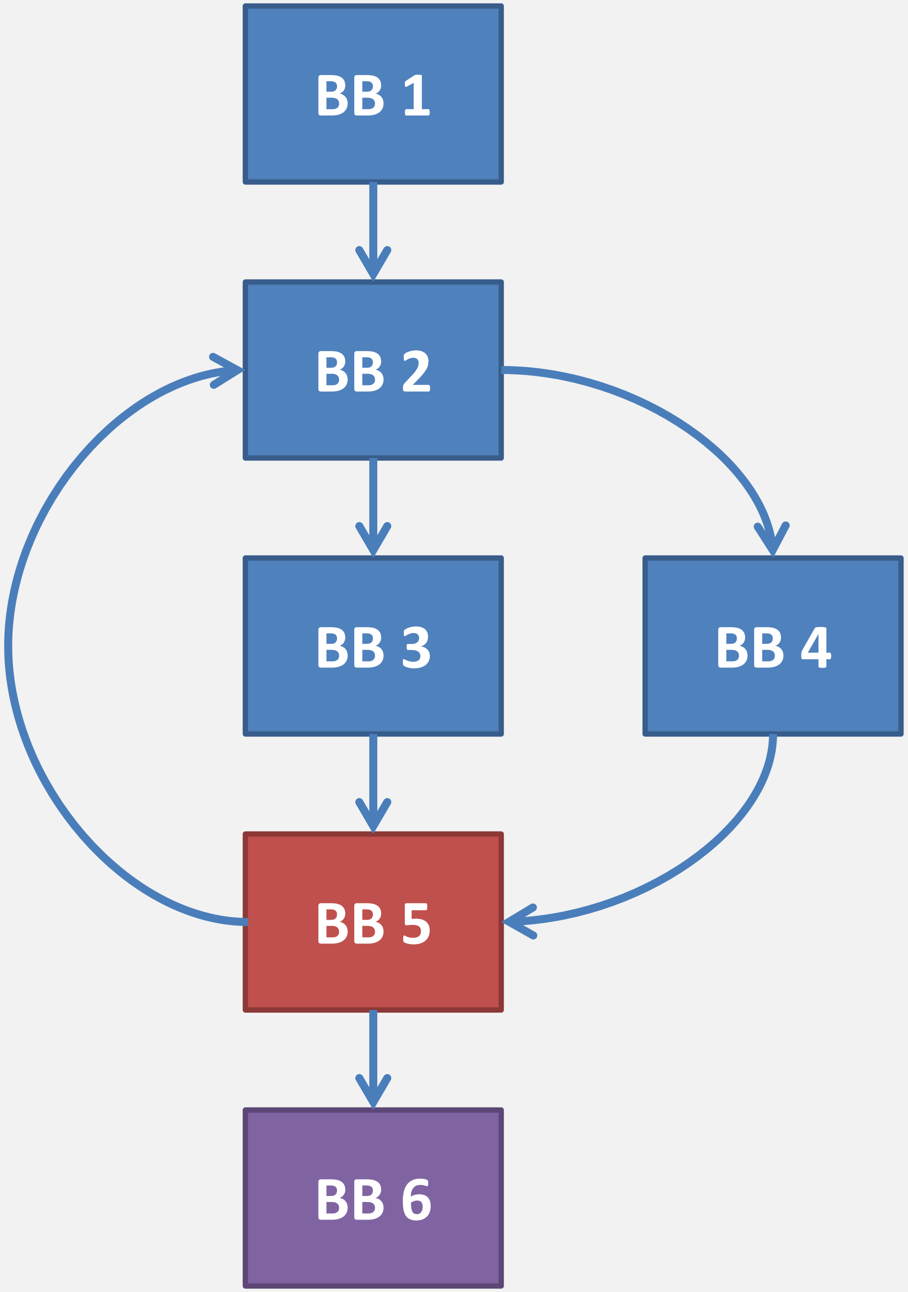
Basic block A <u>immediately dominates</u> Basic Block B if it strictly dominates it, but does not strictly dominate another BB that strictly dominates it



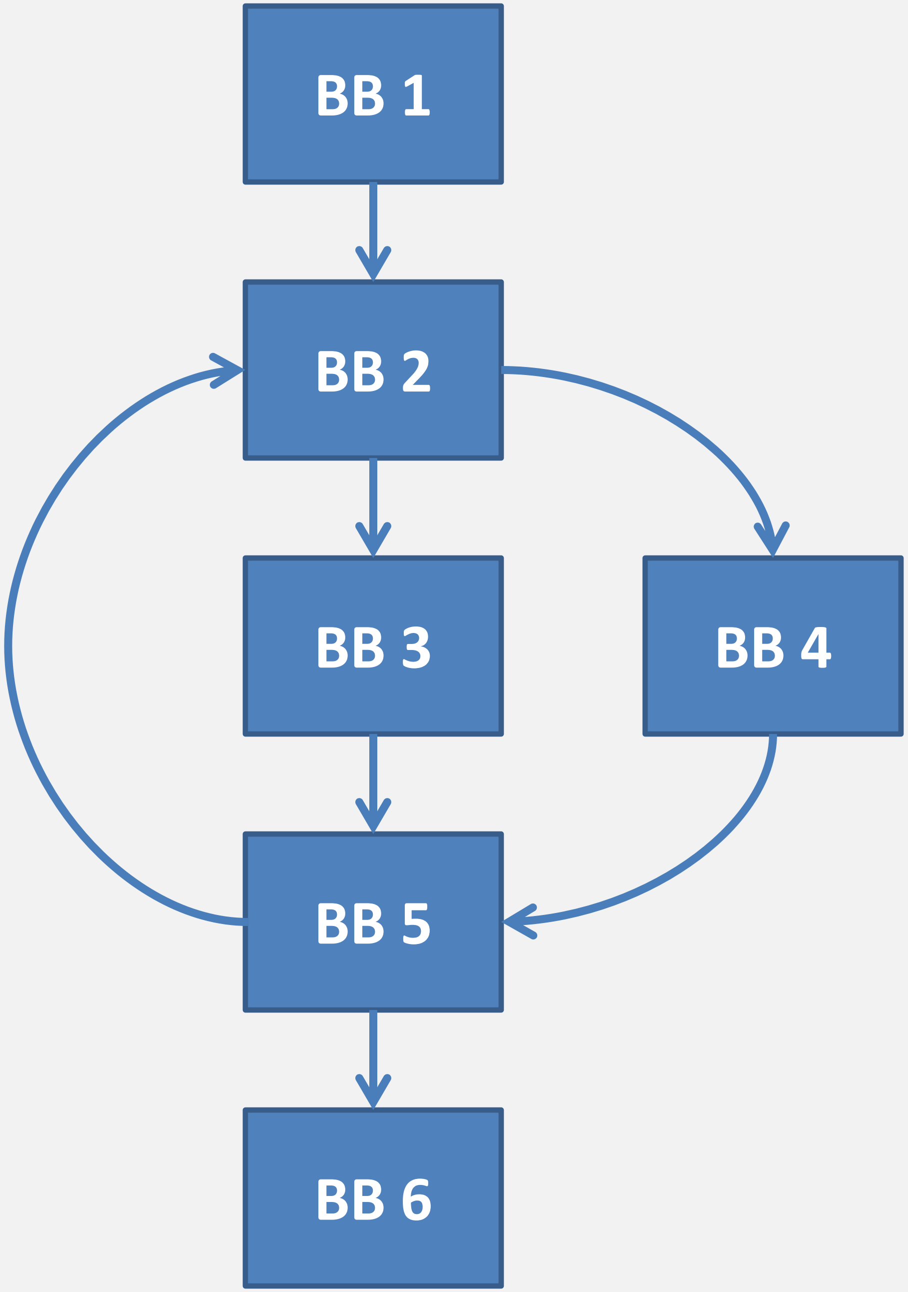
Block	Strictly Dominates
BB1	BB2, BB3, BB4, BB5, BB6
BB2	BB3, BB4, BB5, BB6
BB3	
BB4	
BB5	BB6
BB6	



Block	Strictly Dominates
BB1	BB2, BB3, BB4, BB5, BB6
BB2	BB3, BB4, BB5, BB6
BB3	
BB4	
BB5	BB6
BB6	



Block	Strictly Dominates
BB1	<u>BB2</u>, BB3, BB4, BB5, BB6
BB2	<u>BB3</u>, <u>BB4</u>, <u>BB5</u>, BB6
BB3	
BB4	
BB5	<u>BB6</u>
BB6	

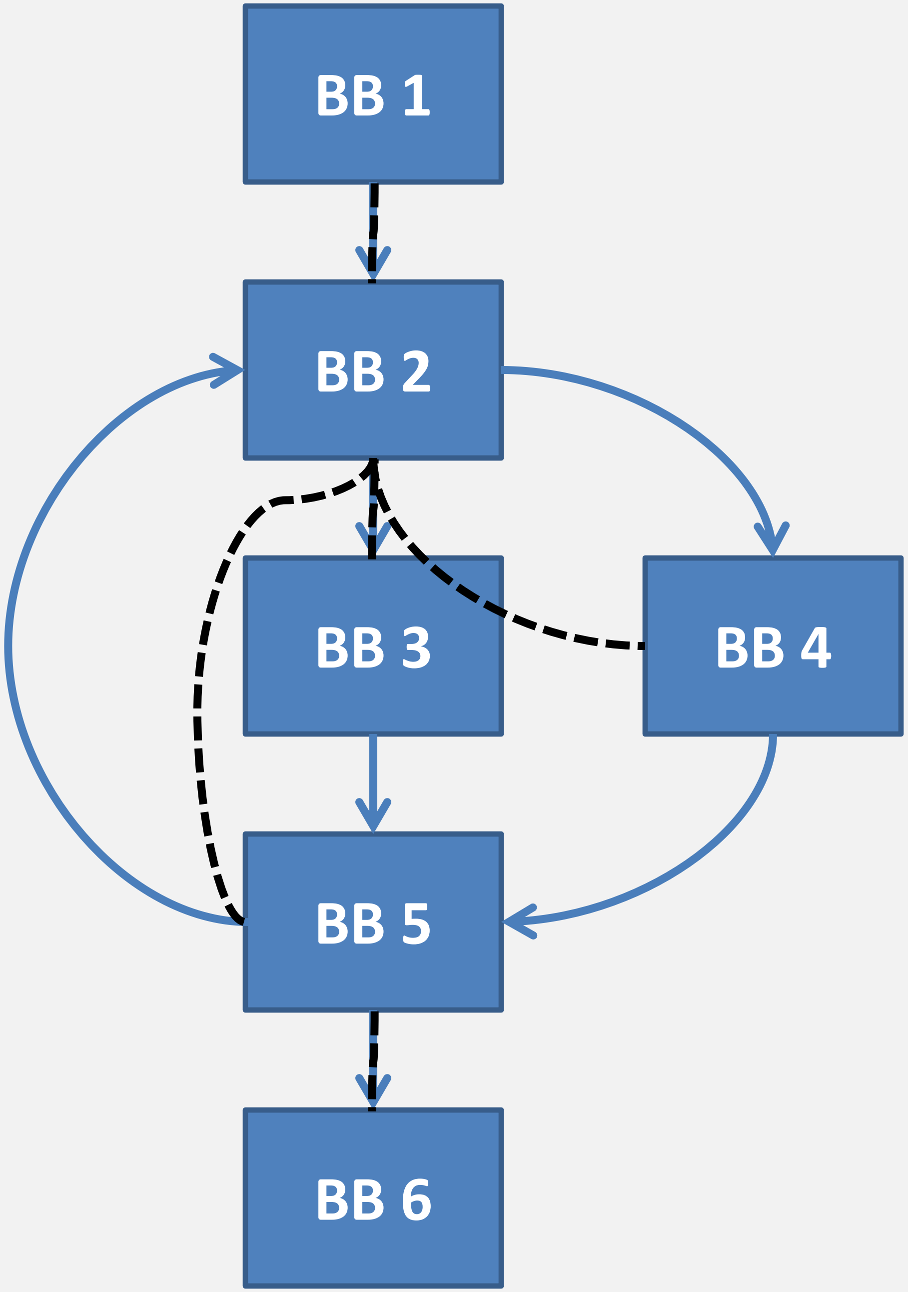


Block	Immediately Dominates
BB1	BB2
BB2	BB3, BB4, BB5
BB3	
BB4	
BB5	BB6
BB6	

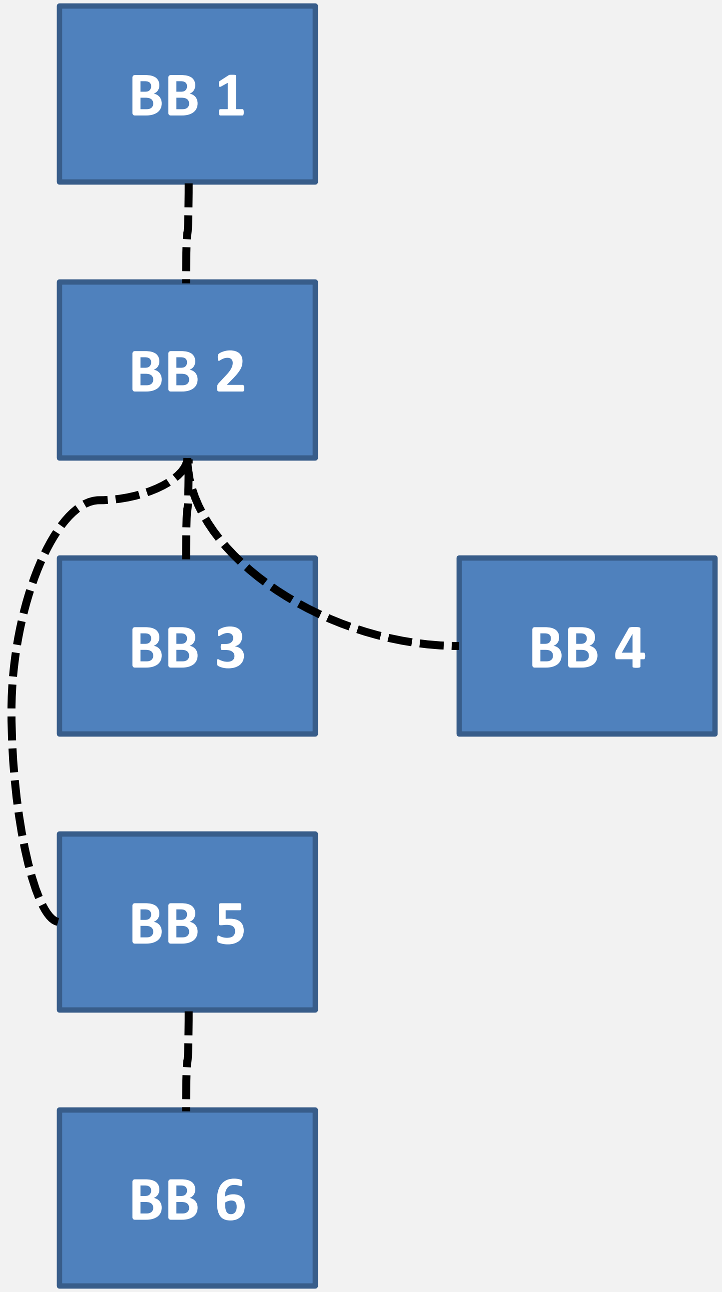
Dominance tree

The immediate dominator of each basic block is unique

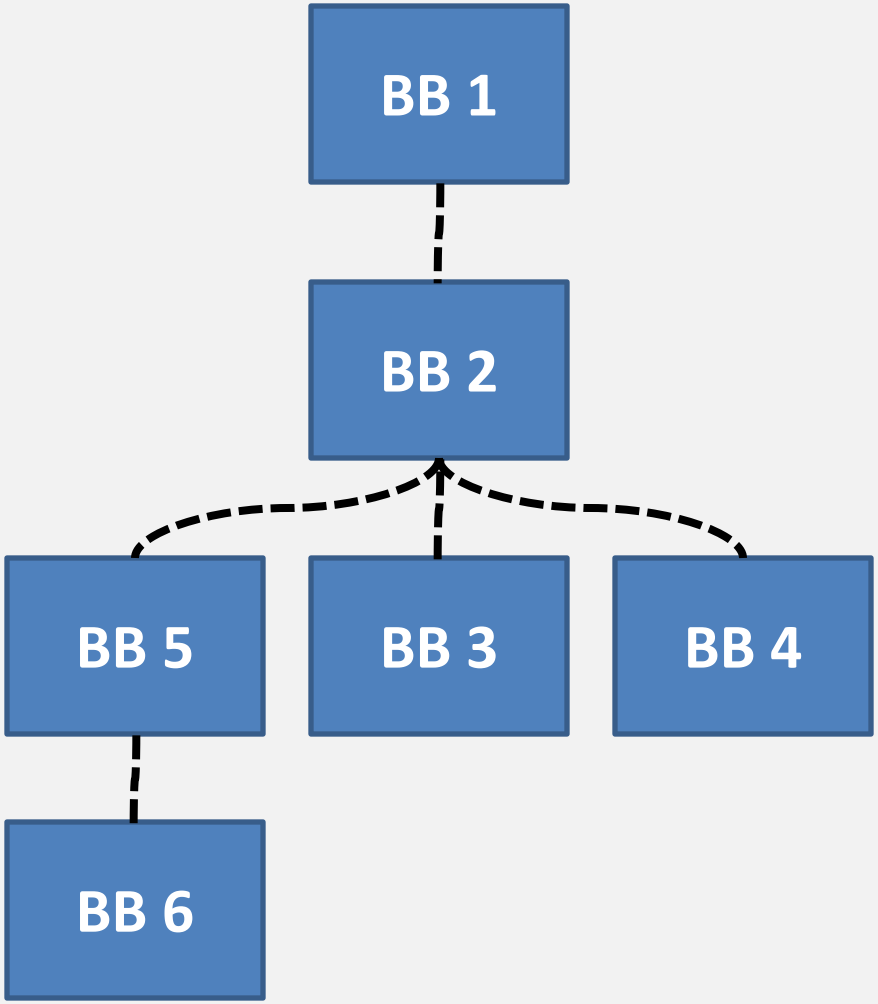
Thus they form a tree, aka the dominance tree



Block	Immediately Dominates
BB1	BB2
BB2	BB3, BB4, BB5
BB3	
BB4	
BB5	BB6
BB6	



Block	Immediately Dominates
BB1	BB2
BB2	BB3, BB4, BB5
BB3	
BB4	
BB5	BB6
BB6	



Block	Immediately Dominates
BB1	BB2
BB2	BB3, BB4, BB5
BB3	
BB4	
BB5	BB6
BB6	

Dominance children

Successor and predecessor are refer to the CFG

Parent and children refer to the dominance tree

Why bother?

The dominance tree is a good order to visit basic blocks to propagate type information

But there's another reason…

Static Single Assignment

Form where each variable only has one (textual) assignment in the program

Can form it by renaming

SSA in linear code: easy

Bump version per assign

```
param_rp_i r0, liti16(0)
param_rp_i r1, liti16(1)
mul_i r0, r0, r0
add_i r0, r0, r1
return_i r0
```

SSA in linear code: easy

Bump version per assign

```
param_rp_i r0(1), liti16(0)
param_rp_i r1, liti16(1)
mul_i r0, r0, r0
add_i r0, r0, r1
return_i r0
```

SSA in linear code: easy

Bump version per assign

```
param_rp_i r0(1), liti16(0)
param_rp_i r1(1), liti16(1)
mul_i r0, r0, r0
add_i r0, r0, r1
return_i r0
```

SSA in linear code: easy

Bump version per assign

```
param_rp_i r0(1), liti16(0)
param_rp_i r1(1), liti16(1)
mul_i r0(2), r0(1), r0(1)
add_i r0, r0, r1
return_i r0
```

SSA in linear code: easy

Bump version per assign

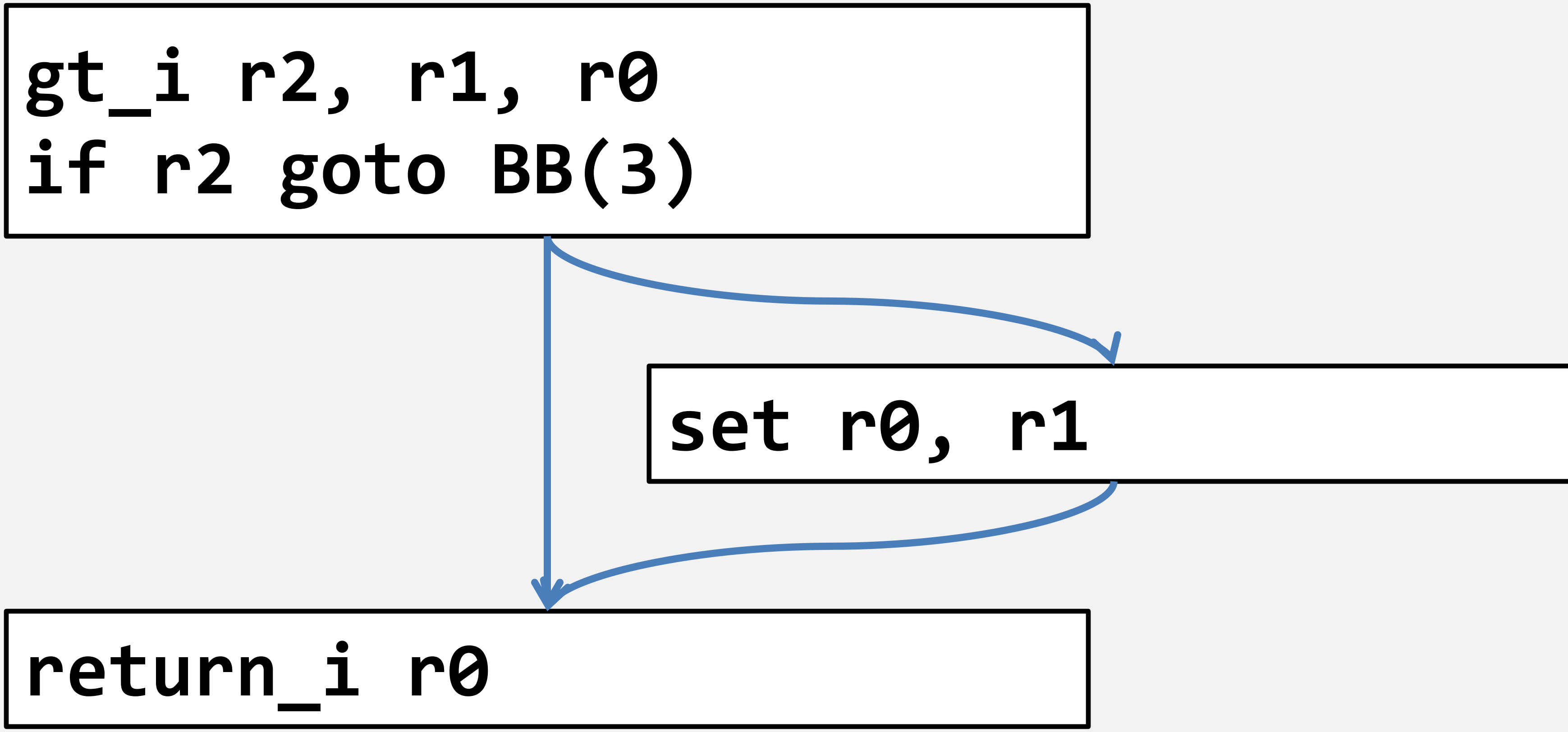
```
param_rp_i r0(1), liti16(0)
param_rp_i r1(1), liti16(1)
mul_i r0(2), r0(1), r0(1)
add_i r0(3), r0(2), r1(1)
return_i r0
```

SSA in linear code: easy

Bump version per assign

```
param_rp_i r0(1), liti16(0)
param_rp_i r1(1), liti16(1)
mul_i r0(2), r0(1), r0(1)
add_i r0(3), r0(2), r1(1)
return_i r0(3)
```

What about flow control?



What about flow control?

```
gt_i r2(1), r1(1), r0(1)
if r2(1) goto BB(3)
```

```
set r0, r1
```

```
return_i r0
```

What about flow control?

```
gt_i r2(1), r1(1), r0(1)
if r2(1) goto BB(3)
```

```
set r0(2), r1(1)
```

```
return_i r0
```

What about flow control?

```
gt_i r2(1), r1(1), r0(1)
if r2(1) goto BB(3)
```

```
set r0(2), r1(1)
```

```
return_i r0(???)
```

PHI functions

At such "join points" in the graph, we insert PHI functions

These "merge" the incoming values

What about flow control?

```
gt_i r2(1), r1(1), r0(1)
if r2(1) goto BB(3)
```

```
set r0(2), r1(1)
```

```
PHI r0(3), r0(1), r0(2)
return_i r0(3)
```

Placing PHIs

Placing PHI functions is also driven by dominance (of note, dominance frontiers - the places that a basic block's strict dominance ends)

Why SSA?

Associate facts with each SSA variable (known type, known concrete, known value), and then can easily look them up and rely on them

And at PHI functions?

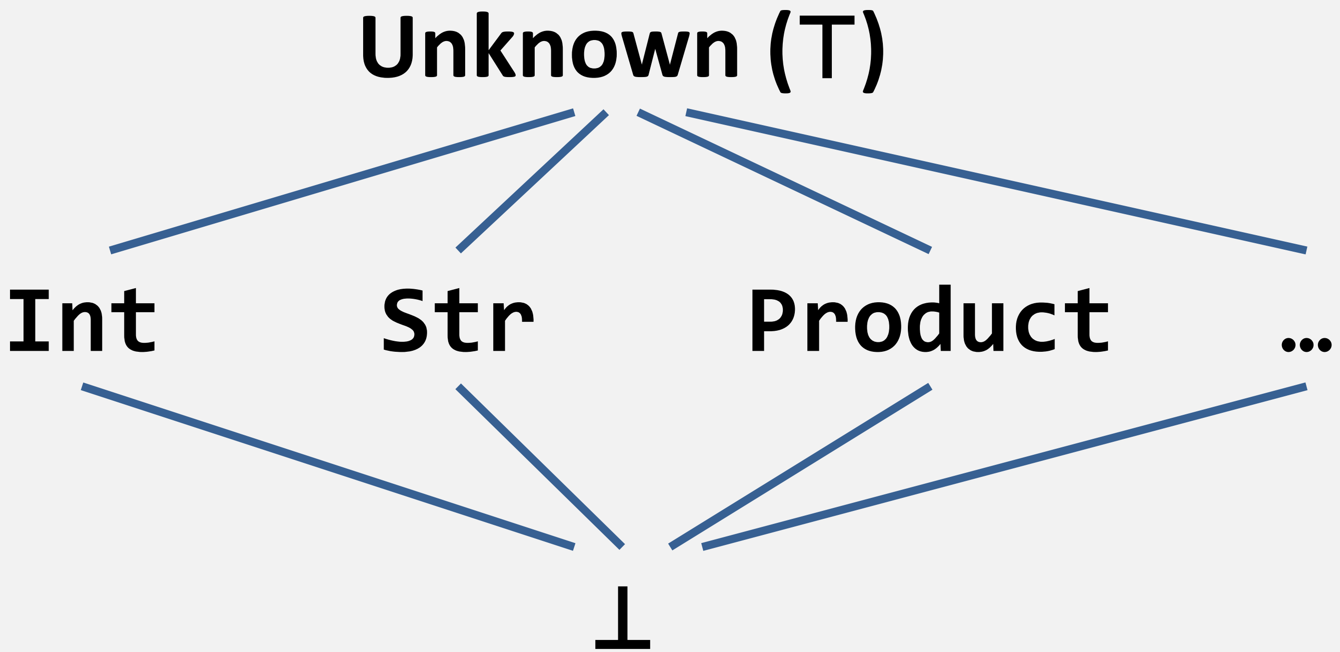
Merge what we know

But how to do it safely?

Use a lattice for each fact type

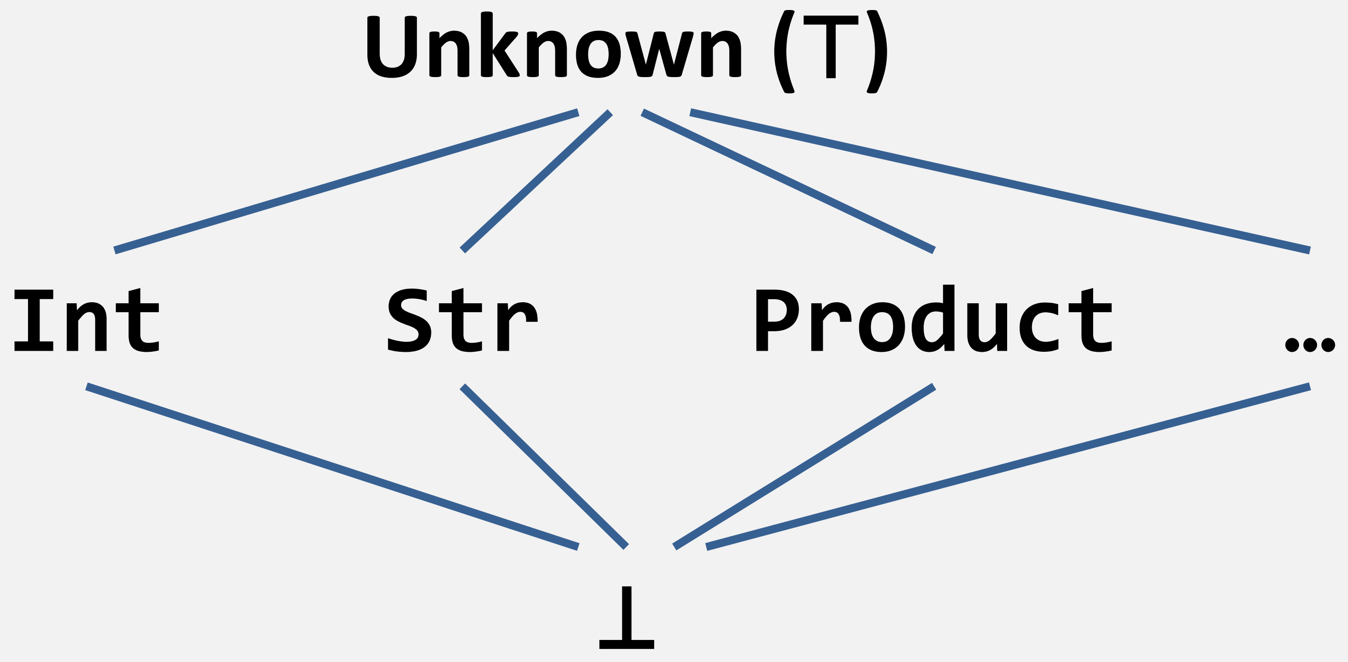
Known type lattice

Easy rule: only move up



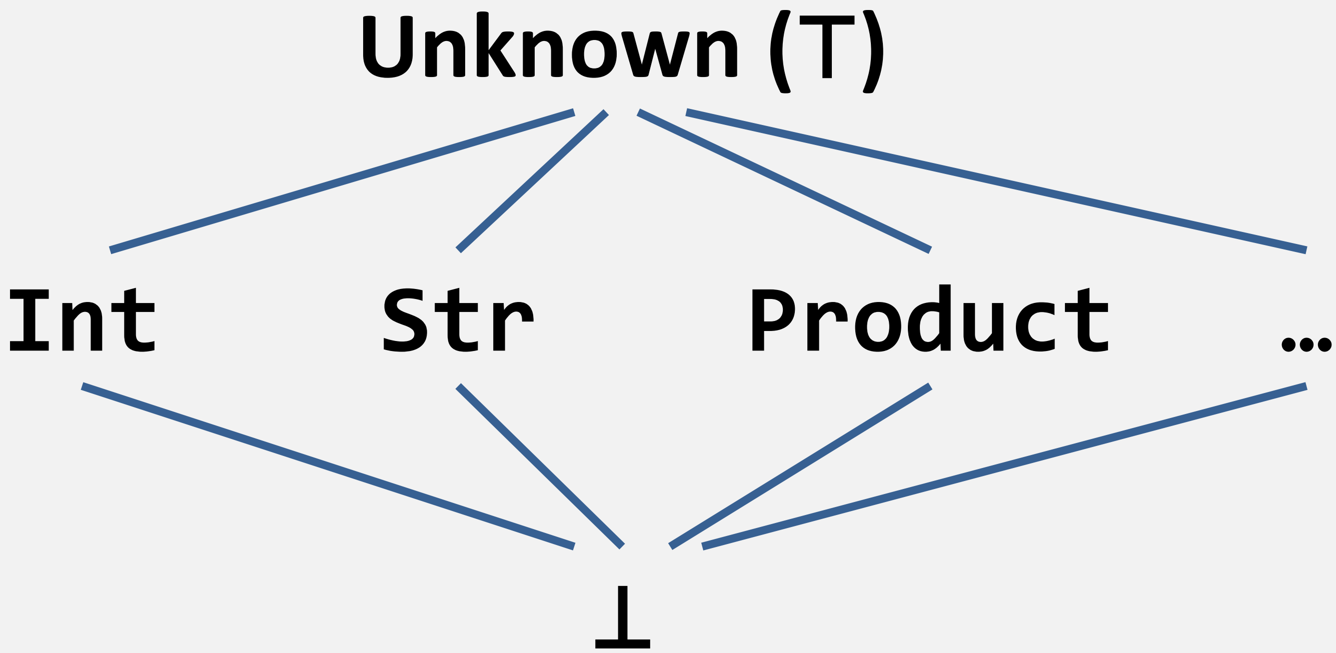
Known type lattice

join(Int, Int) ➔ Int



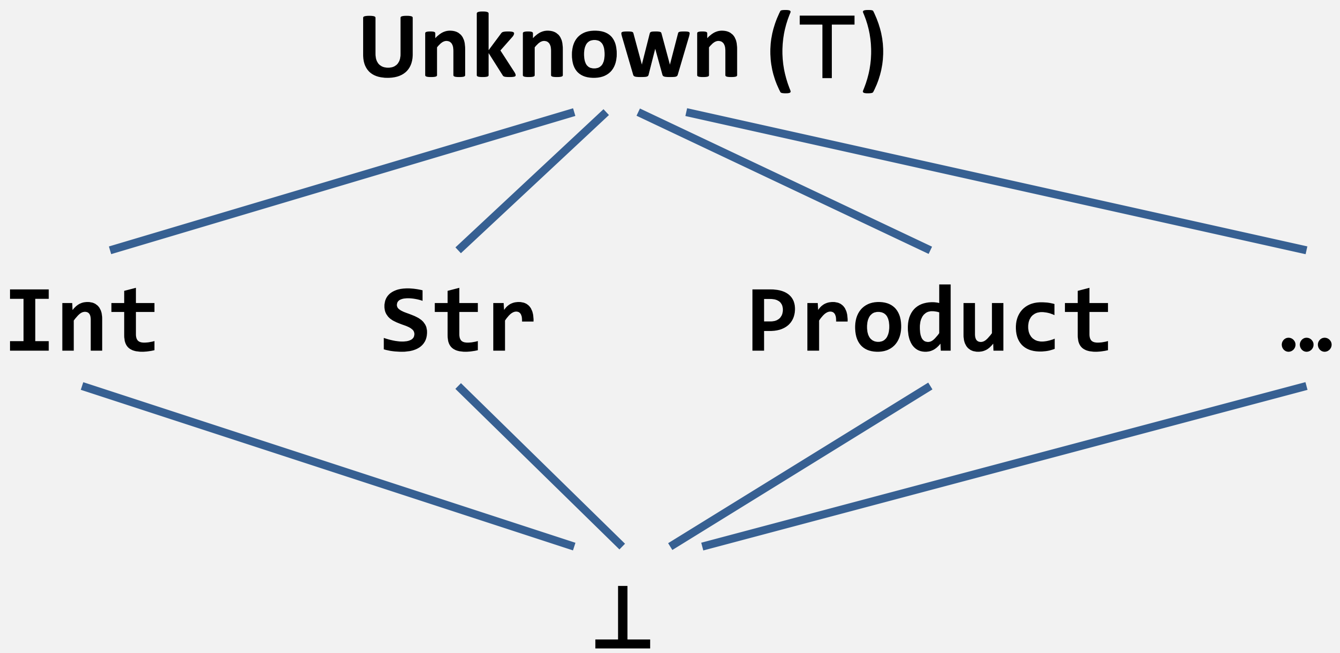
Known type lattice

join(Int, Str) ➔ $\top$



Known type lattice

join(Int, ⊤) ➔ ⊤



Where do facts come from?

Sometimes we refer to a static value (constants, types)

Others come from the statistics

But…

The statistics only mean we <u>tend</u> to have a certain type or code object; they aren't a proof that we always will!

Enter guards

Thus, we insert guard instructions, which quickly check that the actual type etc. encountered is the one the statistics suggest is typical

Deoptimization enables speculation

When a guard fails…

This is when we are forced to perform deoptimization

Fall back to the interpreted code that can handle all cases

Consequence

Must make sure that we preserve enough data so that we can fall back to the interpreter and have it continue

Example: dead code elimination

Some dead writes can't actually be removed, because they'll be needed if we are forced to deoptimize

But generally, we win

Guards are far cheaper than the indirections they replace (and they "hoist" the checks)

Deoptimizations are rare

What about mixins?

Mixins change the types of objects "at a distance"

Force global deoptimization of the whole call stack

Some Optimizations

With a bunch of facts, and guards ensuring they are true, we can now proceed to transform the graph

Resolving method calls

Knowing the exact type lets us resolve method calls directly

Saves a hash lookup in the method cache

Avoiding multi-dispatch

Use the type facts to determine which multi candidate would be called, thus avoiding the overhead of the multi-dispatch cache

Specialization linking

Use argument types to identify which specialization of a callee should be used, avoiding argument type checks in the called code

Inlining

For small callees, replace the call with the code in the callee, avoiding the overhead of creating and tearing down the call frame and arg passing

Aside: uninlining

In order that we can inline, we also have to be able to undo it in deoptimization. This is "uninlining". A bit tricky, but we manage it.

Unchecked attribute accesses

Just read the memory location holding an attribute, rather than having to do a lookup by name (also applies to the value slot of a `Scalar`!)

Checks to constants

Type checks already answered by the established facts can be turned into constants. Same with "is it a container", "is it concrete", etc.

Constant conditional removal

These "new constants" may resolve some conditionals, allowing for removal of the check and branch instructions

Let's see how the chars method was before optimization...

```
checkarity      liti16(1), liti16(1)
param_rp_o        r1(2), liti16(0)
hllize            r8(2),   r1(2)

set               r1(3),   r8(2)
decont            r8(3),   r1(3)

wval              r9(2), liti16(1), liti16(35) (P6opaque: Str)
istype           r10(1),   r8(3),   r9(2)

assertparamcheck  r10(1)

decont            r9(3),   r1(3)

isconcrete       r10(2),   r9(3)
assertparamcheck  r10(2)

decont            r9(4),   r1(3)

set               r0(2),   r9(4)
param_sn          r2(2)
wval              r4(2), liti16(1), liti16(35) (P6opaque: Str)
getattr_s         r5(1),   r0(2),   r4(2), lits($!value), liti16(0)
chars             r6(1),   r5(1)
p6box_i           r4(3),   r6(1)
wval              r7(2), liti16(1), liti16(37) (P6opaque: Int)
decont            r9(5),   r4(3)

istype            r6(2),   r9(5),   r7(2)

unless_i          r6(2),  BB(12)

isconcrete       r10(3),   r9(5)
if_i             r10(3),  BB(15)

wval              r8(4), liti16(1), liti16(21) (P6opaque: Nil)
istype            r6(3),   r9(5),   r8(4)

if_i              r6(3),  BB(15)

wval              r8(5), liti16(4), liti16(8) (not deserialized)
prepargs        callsite(0x7f0b7089da40, 2 arg, 2 pos, nonflattening, interned)
arg_o           liti16(0),   r4(3)
arg_o           liti16(1),   r7(2)
invoke_v          r8(5)

return_o          r4(3)
```

```
checkarity      liti16(1), liti16(1)
param_rp_o        r1(2), liti16(0)
hllize            r8(2),   r1(2)

set               r1(3),   r8(2)
decont            r8(3),   r1(3)

wval              r9(2), liti16(1), liti16(35) (P6opaque: Str)
istype           r10(1),   r8(3),   r9(2)

assertparamcheck  r10(1)

decont            r9(3),   r1(3)

isconcrete       r10(2),   r9(3)
assertparamcheck  r10(2)

decont            r9(4),   r1(3)

set               r0(2),   r9(4)
param_sn          r2(2)
wval              r4(2), liti16(1), liti16(35) (P6opaque: Str)
getattr_s         r5(1),   r0(2),   r4(2), lits($!value), liti16(0)
chars             r6(1),   r5(1)
p6box_i           r4(3),   r6(1)
wval              r7(2), liti16(1), liti16(37) (P6opaque: Int)
decont            r9(5),   r4(3)

istype            r6(2),   r9(5),   r7(2)

unless_i          r6(2),  BB(12)

isconcrete       r10(3),   r9(5)
if_i             r10(3),  BB(15)

wval              r8(4), liti16(1), liti16(21) (P6opaque: Nil)
istype            r6(3),   r9(5),   r8(4)

if_i              r6(3),  BB(15)

wval              r8(5), liti16(4), liti16(8) (not deserialized)
prepargs        callsite(0x7f0b7089da40, 2 arg, 2 pos, nonflattening, interned)
arg_o           liti16(0),   r4(3)
arg_o           liti16(1),   r7(2)
invoke_v          r8(5)

return_o          r4(3)
```

Argument handling, type and definedness checks

The work

Return value type check, including letting Nil pass by

Now here's the chars method after specialization and optimizations…

```
sp_getarg_o         r8(2), liti16(0)
set                 r1(3),   r8(2)
set                 r9(3),   r1(3)
const_i64_16       r10(2), liti16(1)
set                 r9(4),   r1(3)
set                 r0(2),   r9(4)
sp_p6oget_s         r5(1),   r0(2), liti16(8)
chars               r6(1),   r5(1)
p6box_i             r4(3),   r6(1)
wval                r7(2), liti16(1), liti16(37)
set                 r9(5),   r4(3)
return_o            r4(3)
```

One basic block, so all the possible invokish things have been devirtualized

All type checks removed

And, yes, a bunch of (cheap) set instructions that we'd like to get rid of in the future (mostly from overzealous deopt safety)

Producing Machine Code

No time for details, but as a next step, we can then compile this into x64 machine code, eliminating the overhead of interpretation

(See video of brrt's TPCiA talk)

Specialization Entry (and Reentry)

So, how do we transition from slow-path interpreted code into specialized code?

Entry on invoke

See if the callsite and argument types match any specialization ("guard tree")

Use that which matches

On Stack Replacement

At the end of a loop body, check if there's an optimized version of the loop code; replace the running code "on stack" with it if there is

Reentry

What if a hot loop deopts one time in a hundred or so?

OSR can put us back into the optimized version again later

Future Plans

Box/unbox elimination, native reference elimination

To avoid allocating temporary box and reference objects, thus saving work immediately and causing less GC overhead

Escape analysis

Work out when an allocation doesn't escape a call, and replace it with a "stack" allocation rather than a "heap" (GC) allocation

More precise deopt handling

Current approach is safe, but decidedly coarse; it can't account for effects of guards that were added, but in the end weren't used

More aggression on inlines

We don't yet propagate facts into the inlines; we could get further improvements to the code if we were able to do so

More tooling

Today, you can set the MVM_SPESH_LOG=a_file environment variable and read the (giant) output; a nicer tool would be good

That's all, folks!

Questions?