YETI: Gradually Extensible Trace Interpreter

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(thesis proposal)

Overview

- Introduction
- Background
- Efficient Interpretation
- Our Approach to Mixed-Mode Execution
- Results and Discussion

Why so few JIT compilers?

- Complex JIT infrastructure built in “big bang”, before any generated code can run.
- Rather than incrementally extend the interpreter, typical JITs is built alongside.
  - The code generator of current JIT compilers makes little provision to reuse the interpreter.
  - The method-orientation of most JITs means that cold code is compiled with hot.

▸ Interpreters should be more gradually extensible to become dynamic compilers.

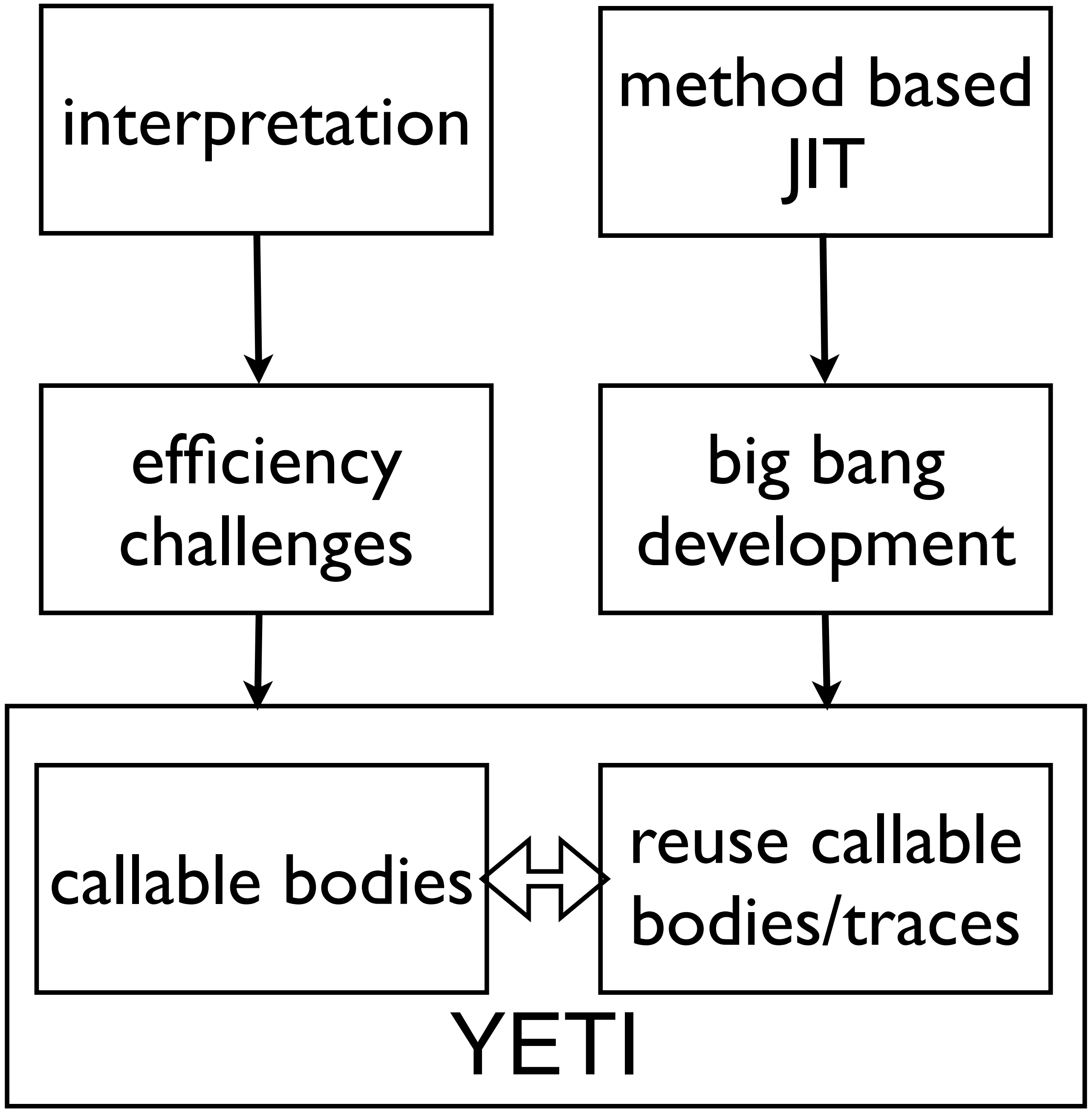
Problems with current practice

- Packaging of virtual instruction bodies is:
  - Inefficient: Interpreters slowed by branch misprediction
  - Non-reusable: JIT compilers must implement all virtual instructions from scratch
- Method orientation of a JIT compiler forces it to compile cold code along with hot.
  - Code compiled cold requires complex runtime to perform late binding if it runs.
  - Recompiling cold code that becomes hot requires complex recompilation infrastructure.

Our Approach

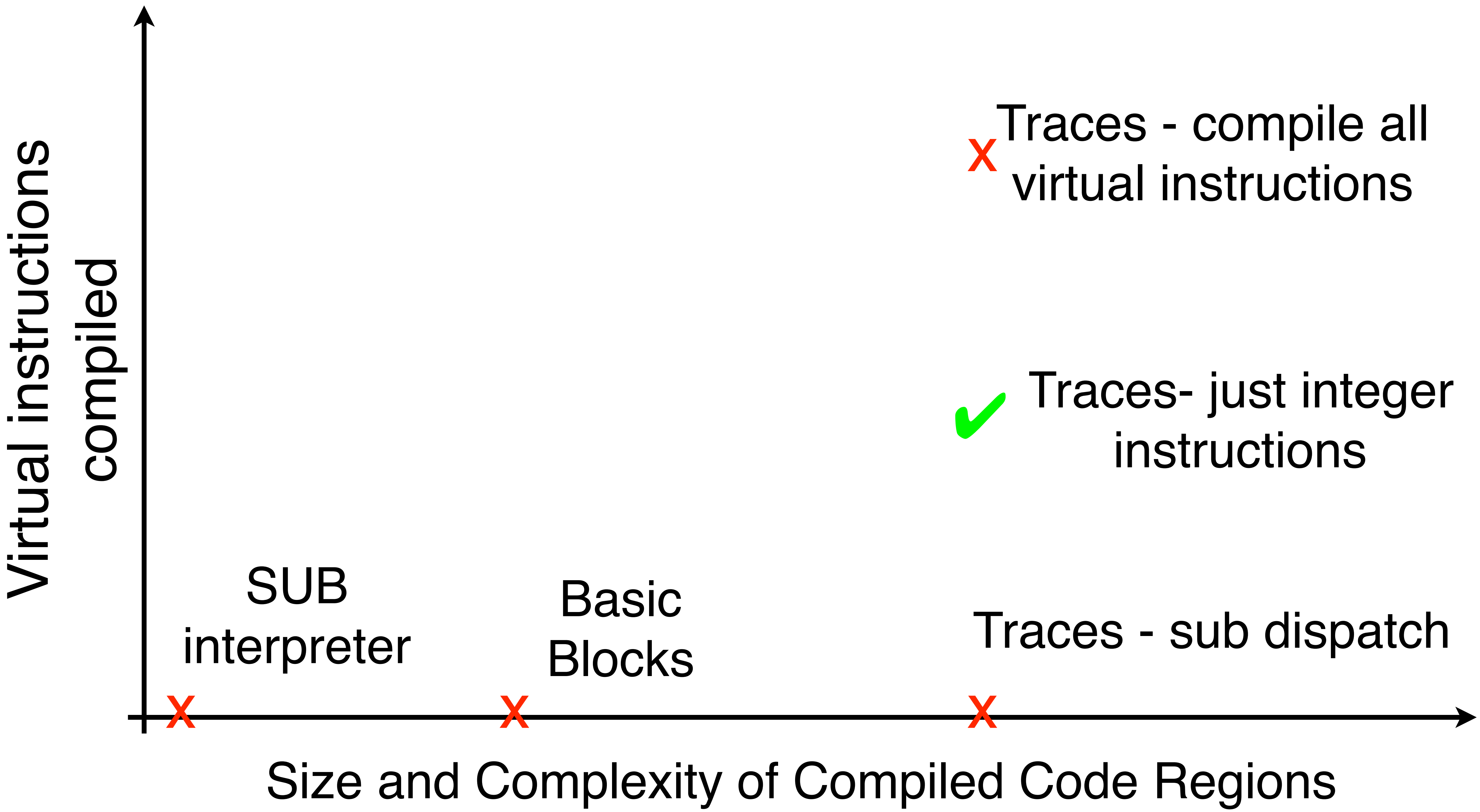
- Branch prediction problems of interpretation can be addressed by *calling* the virtual bodies.
  - Can speed up interpretation significantly.
  - Enables generated code to call the bodies.
  - JIT need not support all virtual instructions.
- Complexity of compiling cold code can be side stepped by compiling dynamically selected regions that contain only hot code.
  - We describe how compiling *traces* allows us to compile only hot code and link on newly hot regions as they emerge.
  - Enables gradual enhancement of interpreter

Overview of Contribution



- Callable bodies make for efficient interpretation.
- Reuse of callable bodies from generated code smooths "big bang".
- A trace oriented JIT compiler is a simple and promising architecture.

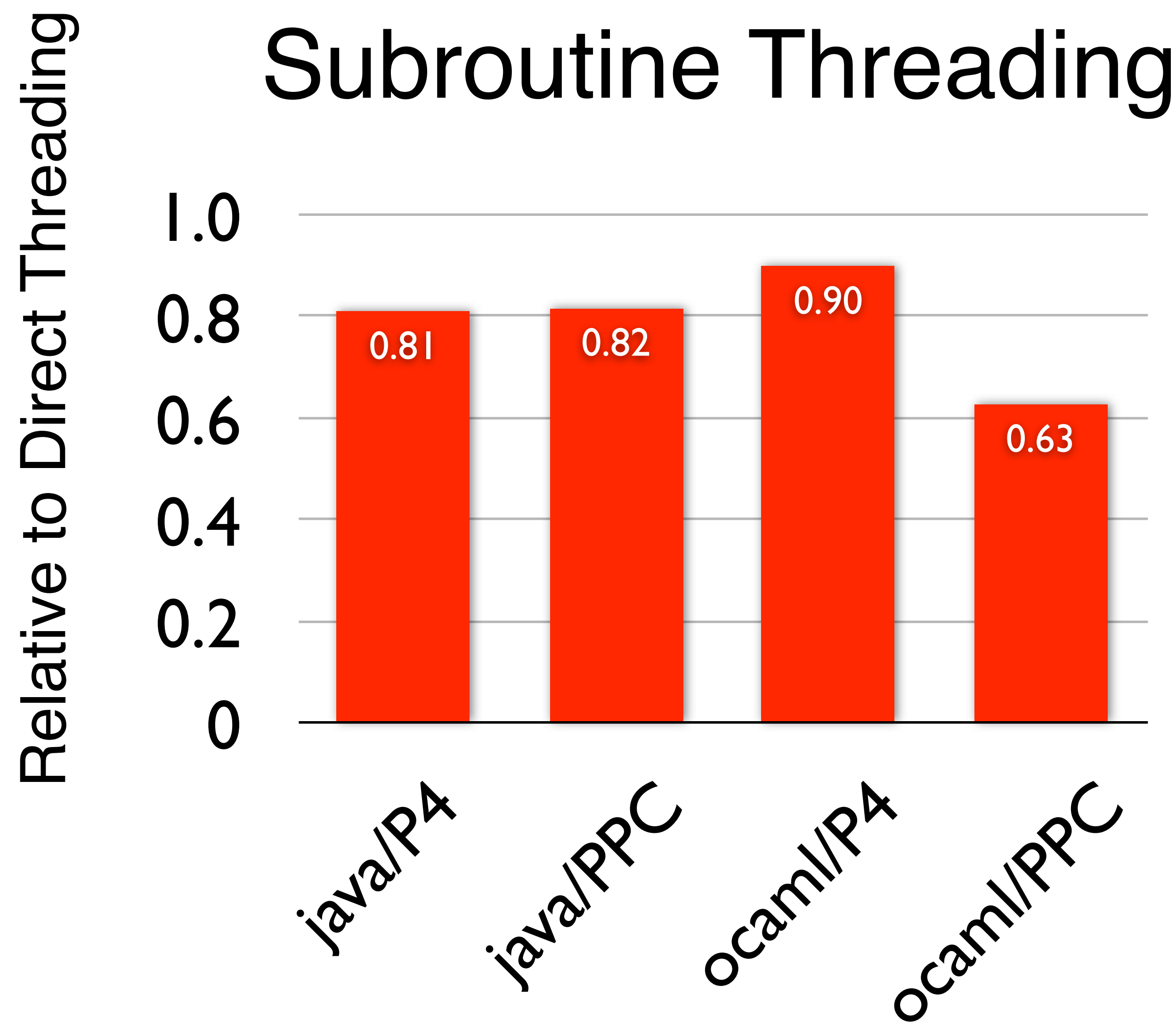
Gradual extension of VM



- Larger regions. More instructions compiled.

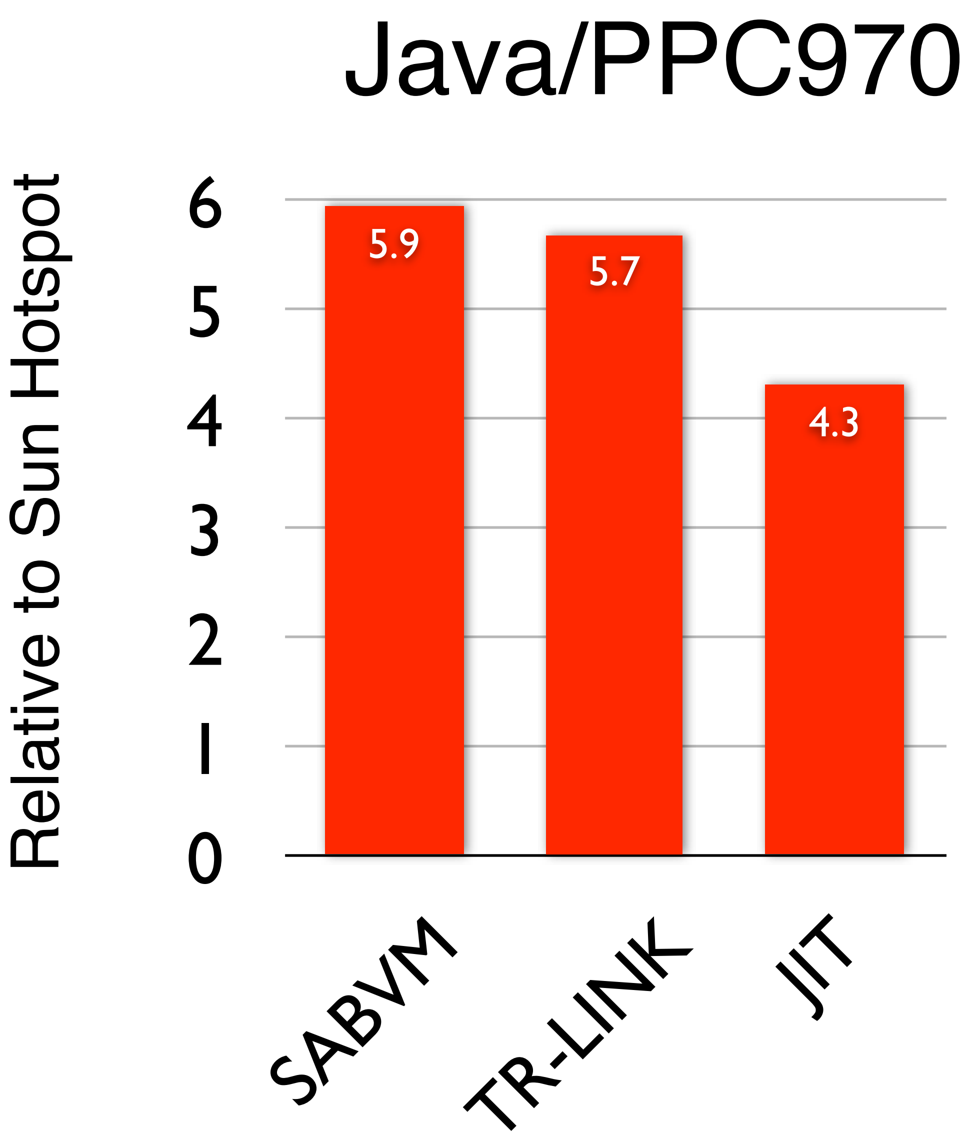
Result preview - Efficient Interpretation

- Branch misprediction dealt with by calling the bodies from region of generated code.
- Relative to Direct Threaded VM
- Geo mean
  - Java SpecJVM98 benchmarks
  - Ocaml benchmarks



Result preview - Trace based JIT

- Geom mean SPECJVM98 relative to Sun Hotspot JIT
- SABVM
  - Selective inlining
- Modified JamVM.
  - TR-LINK = traces,no JIT
  - JIT = trace, JIT
    - Only 50 integer bytecodes
    - Promising start



Background & Related Work

Ertl & Gregg	Branch misprediction
Piumarta & Riccardi	Selective inlining
Parrot (perl6)	Callable bodies
Vitale, Abdelrahman	Catenation, Tcl
Bala, Duesterwald, Banerjia	Dynamo
Bruening, Garnett ,Amarasinghe	Dynamo Rio
Whaley	Partial methods
Gal, Probst, Franz	Hotpath, Trace-based JIT
Suganuma,Yasue,Nkatani	Region based compilation
Hozle, Chambers, Ungar	Self
Many Java, JVM and JIT authors	Java

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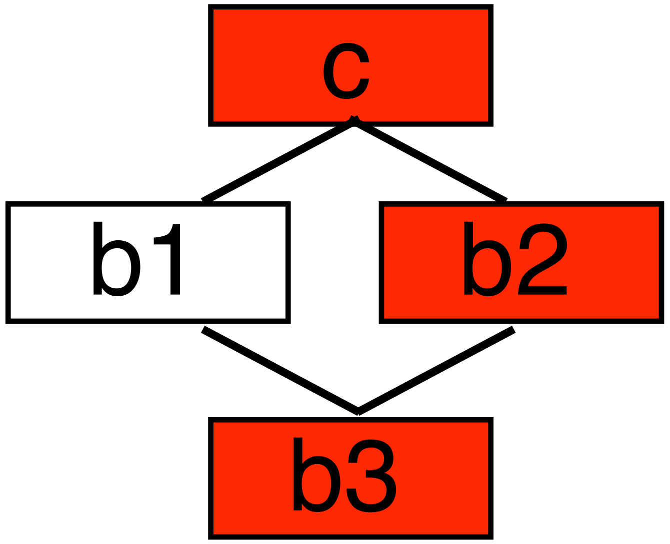
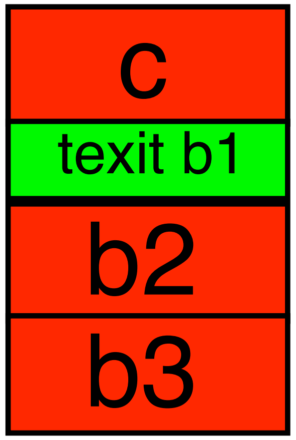
HP Dynamo

- Trace-oriented dynamic optimization system.
  - HP PA-8000 computers.
- Counter-Intuitive approach:
  - Don’t *execute* optimized binary *interpret* it.
  - Count transits of reverse branches.
  - Trace-generate (next slide).
  - Dispatch traces when encountered.
- Soon, most execution from trace cache.
  - *faster* than binary on hardware of the day!

Trace with if-then-else

```
//c => b2
if (c)
    b1;
else
    b2;
b3;
```





- Trace is path followed by program
- Conditional branches become *trace exits*.
- Do *not* expect trace exits to be taken.

Overview

- Introduction
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  - Interpretation
- Efficient Interpretation
- Our Approach
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Virtual Program

Java
Source

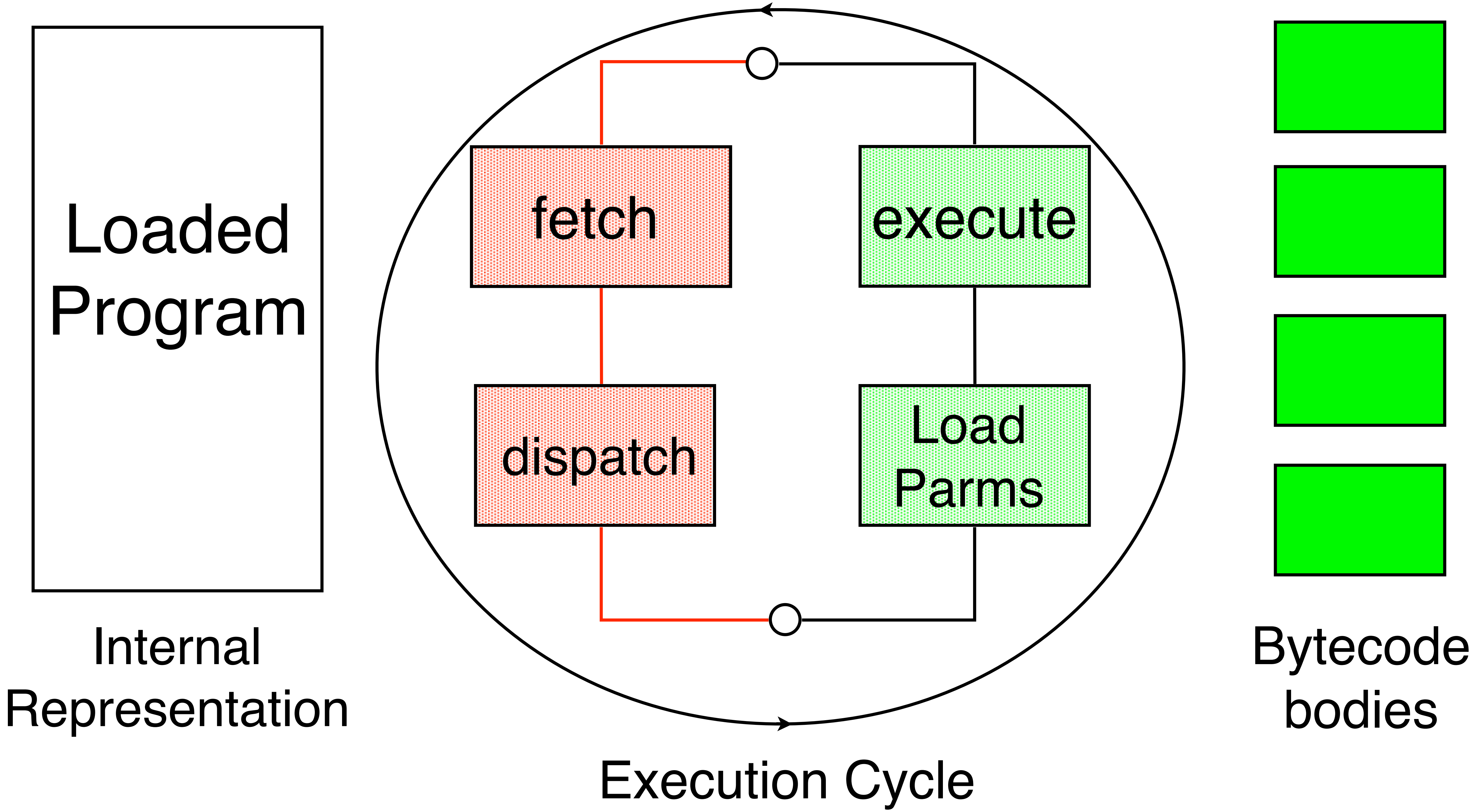
```
int f(boolean parm){
  if (parm){
    return 42;
  }else{
    return 0;
    }
 }
```

Javac
compiler

Java
Bytecode

```
int f(boolean);
  Code:
   0: iload_1
   1: ifeq  7
   4: bipush   42
   6: ireturn
   7: iconst_0
   8: ireturn
```

Interpreter



Switched Interpreter

```
vPC = internalRep;

while(1){
 switch(*vPC++){
   case iload_1:
        ..
      break;

   case ifeq:
        ..
      break;

   //and many more..

   }
};
```

- slow. Burdened by switch and loop overhead.

Call Threaded Interpreter

```
void iload_1(){
 //push load 1
 vPC++;
 }
```

```
void ifeq(){
 //change vPC
 vPC++;
 }
```

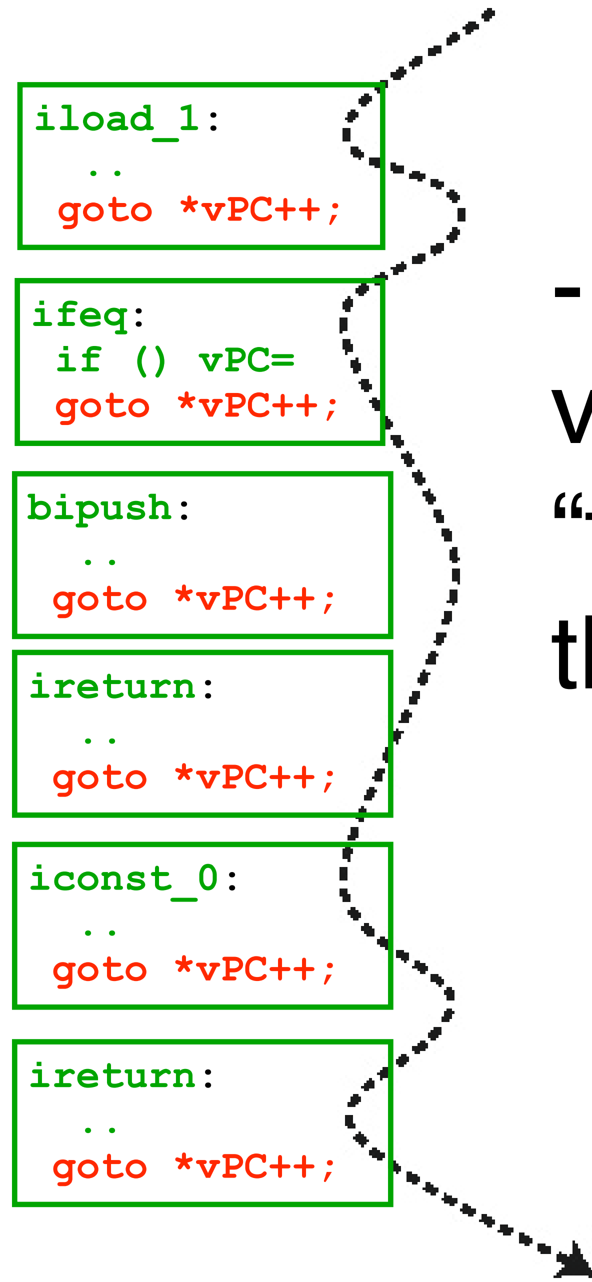
```
static int *vPC = internalRep;

interp(){
  while(1){
     (*vPC)();
     }
  };
```

- slow. burdened by function pointer call

Direct Threaded Interpreter

```
int f(boolean);
  Code:
    0: iload_1
    1: ifeq  7
    4: bipush   42
    6: ireturn
    7: iconst_0
    8: ireturn
```

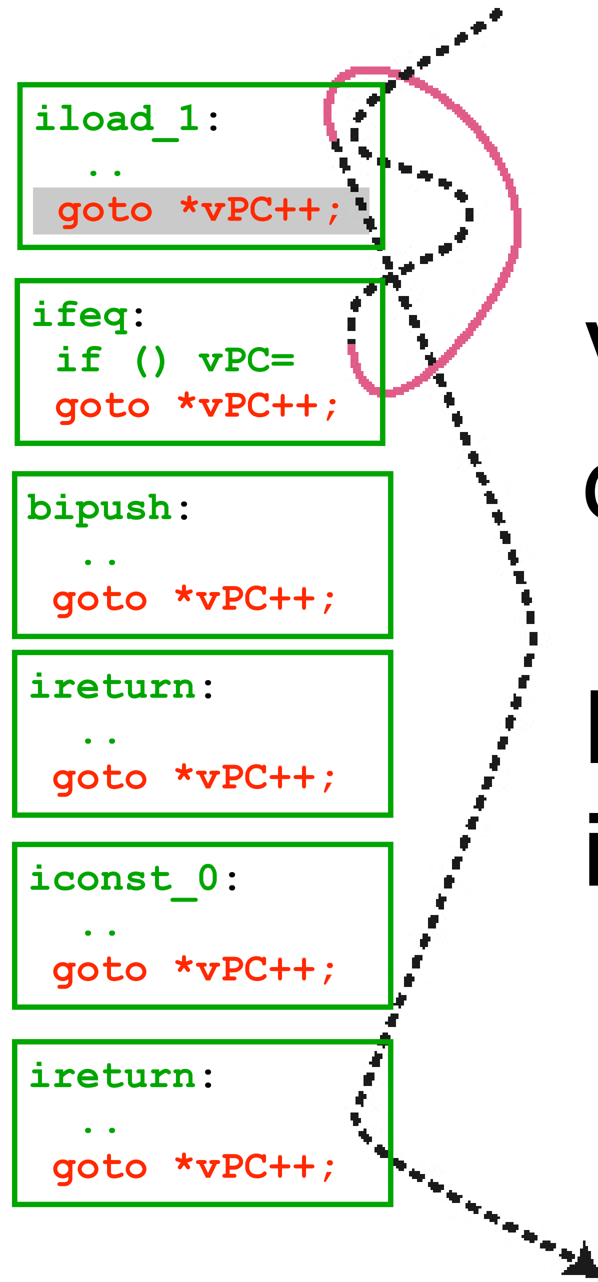


-Execution of virtual program "threads" through bodies

- Good: one dispatch branch taken per body

Context Problem

```
int f(boolean);
  Code:
    0: iload_1
    1: ifeq  7
    4: bipush   42
    6: ireturn
    7: iload_1
    8: ireturn
```



Virtual PC predicts destination.

Hardware PC insufficient context

- Bad: hardware has no context to predict dispatch

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Virtual Program

Java Source

```
int f(boolean parm){
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  }else{
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  }
}
```

Javac compiler

Java Bytecode

```
int f(boolean);
  Code:
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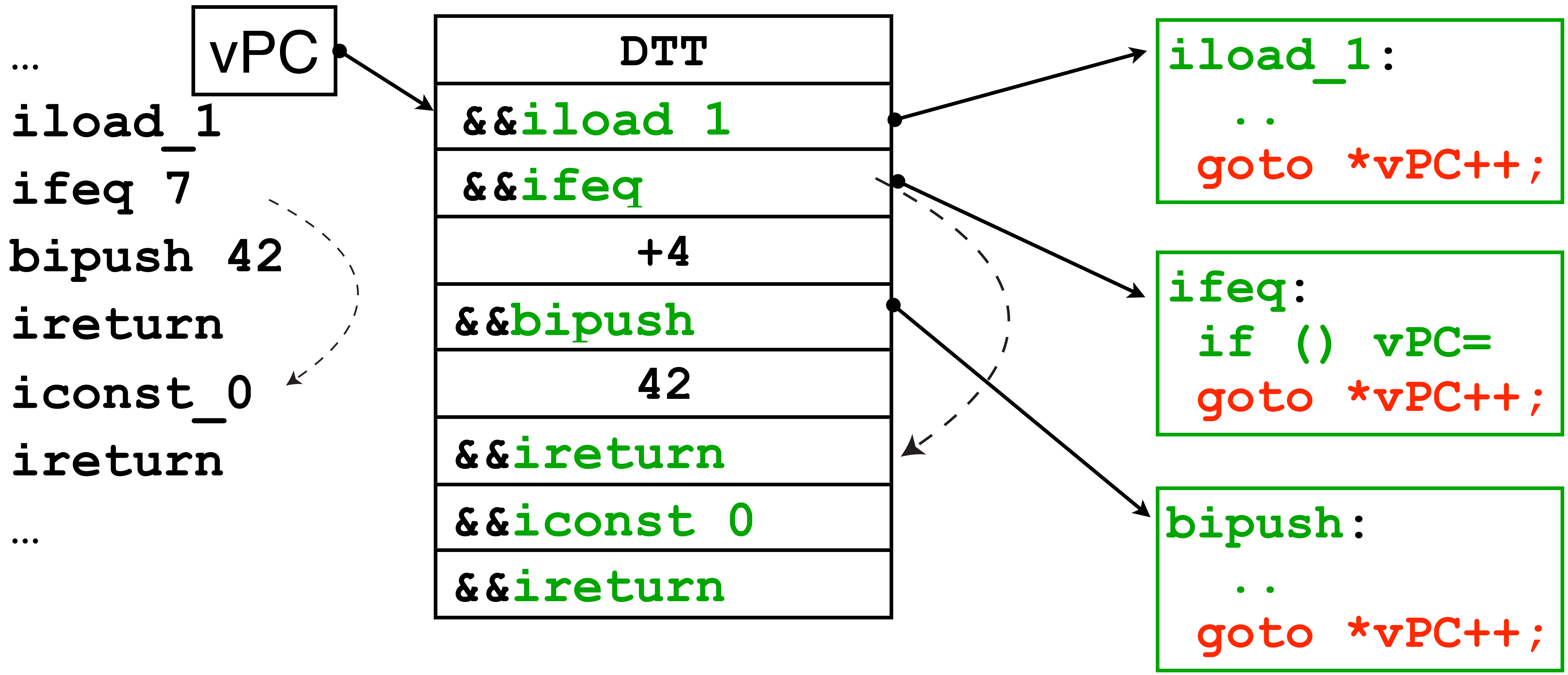
   7: iconst_0
   8: ireturn
```

Direct Threaded Interpreter



Virtual Program

DTT - Direct Threading Table

C implementation of each body

- DTT maps vPC to implementation

Context Problem

```
int f(boolean);
  Code:
    0: iload_1
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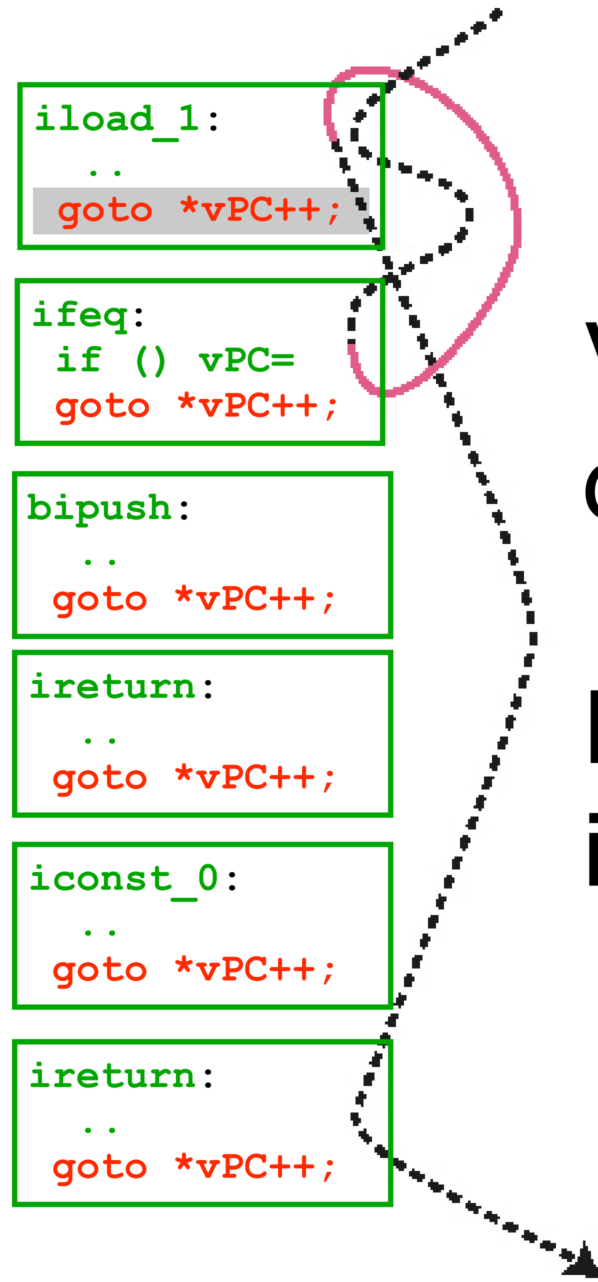
    6: ireturn
    7: iload_1
    8: ireturn
```



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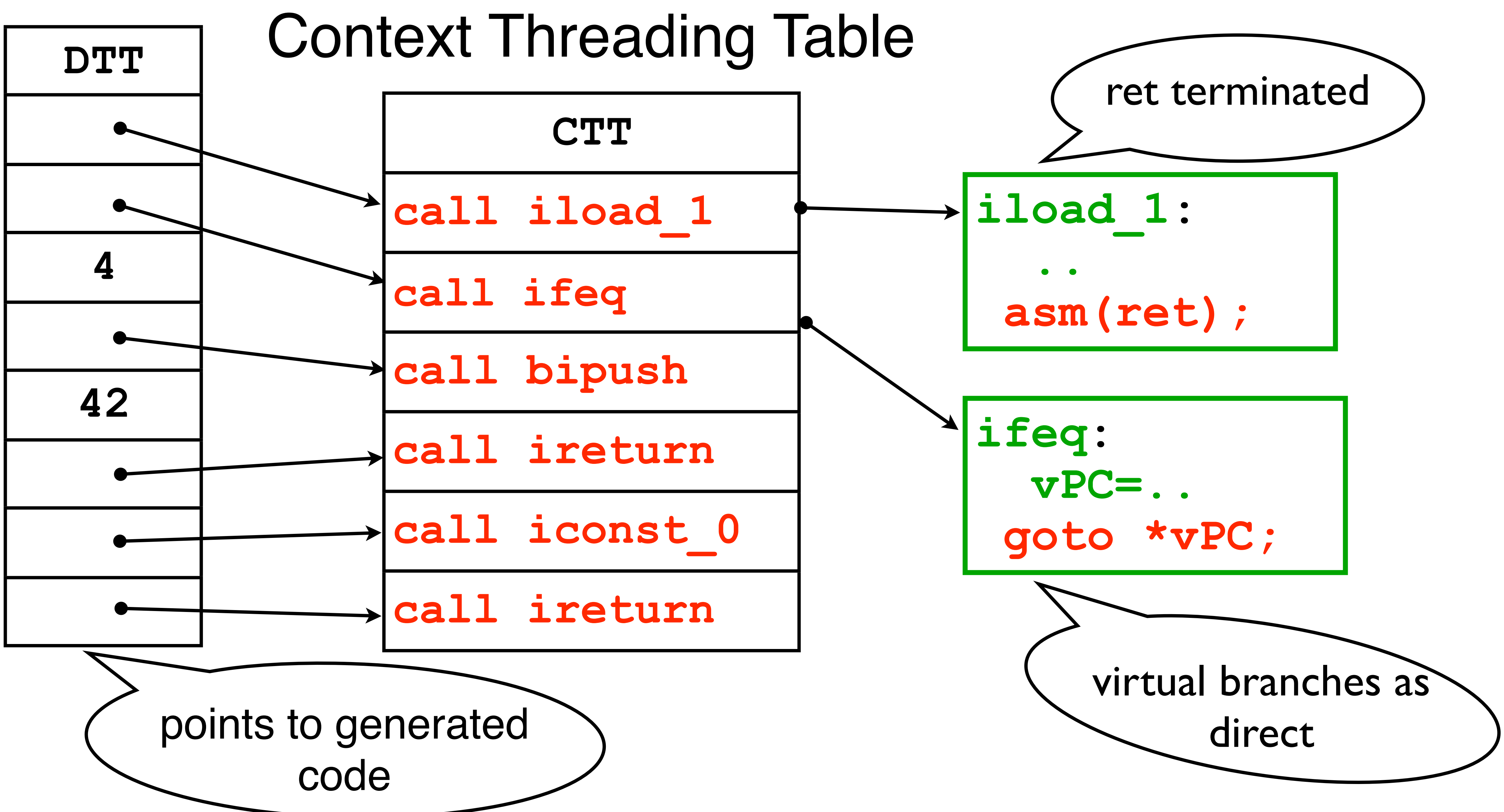
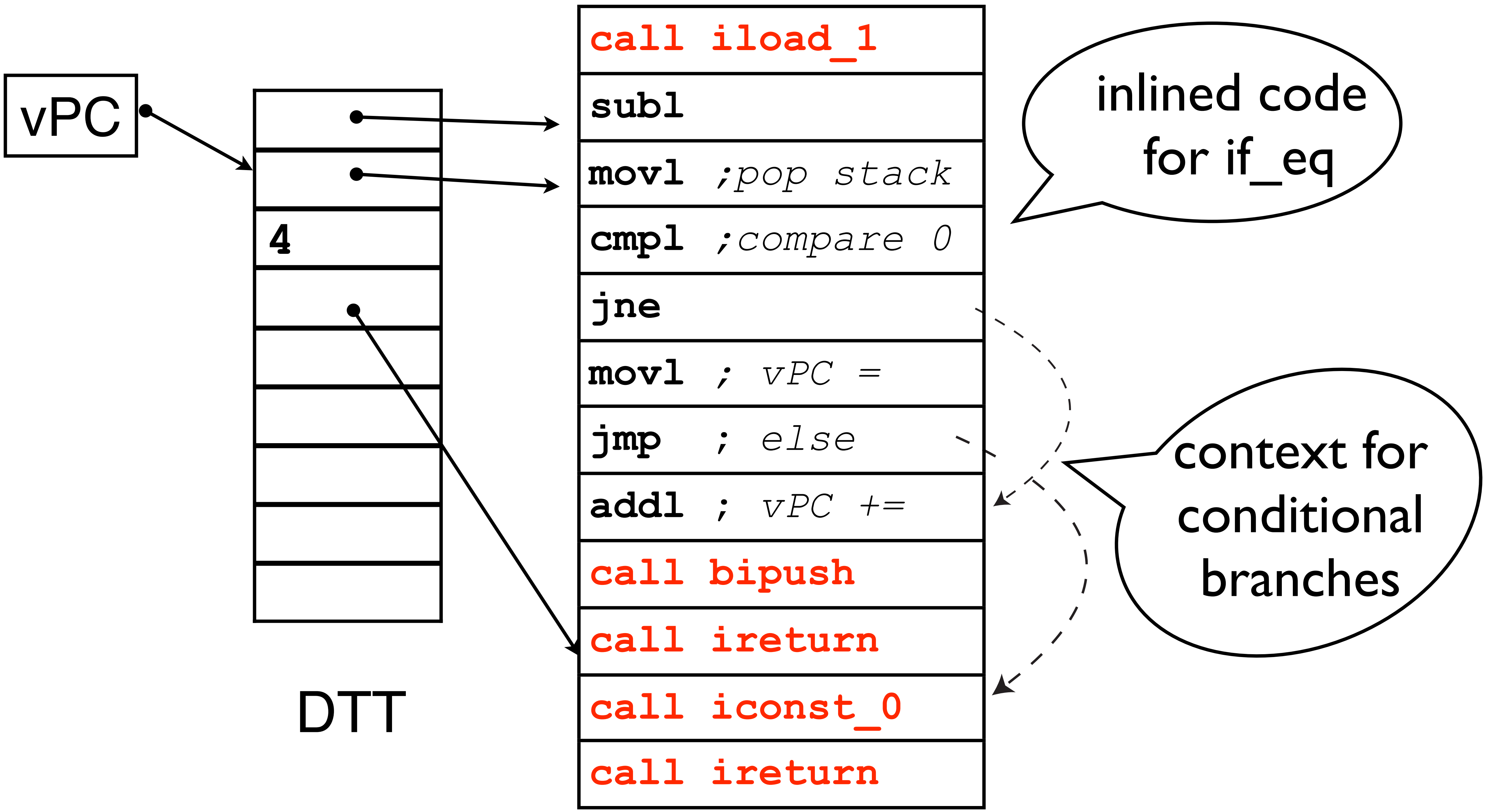
Essence of Subroutine Threading



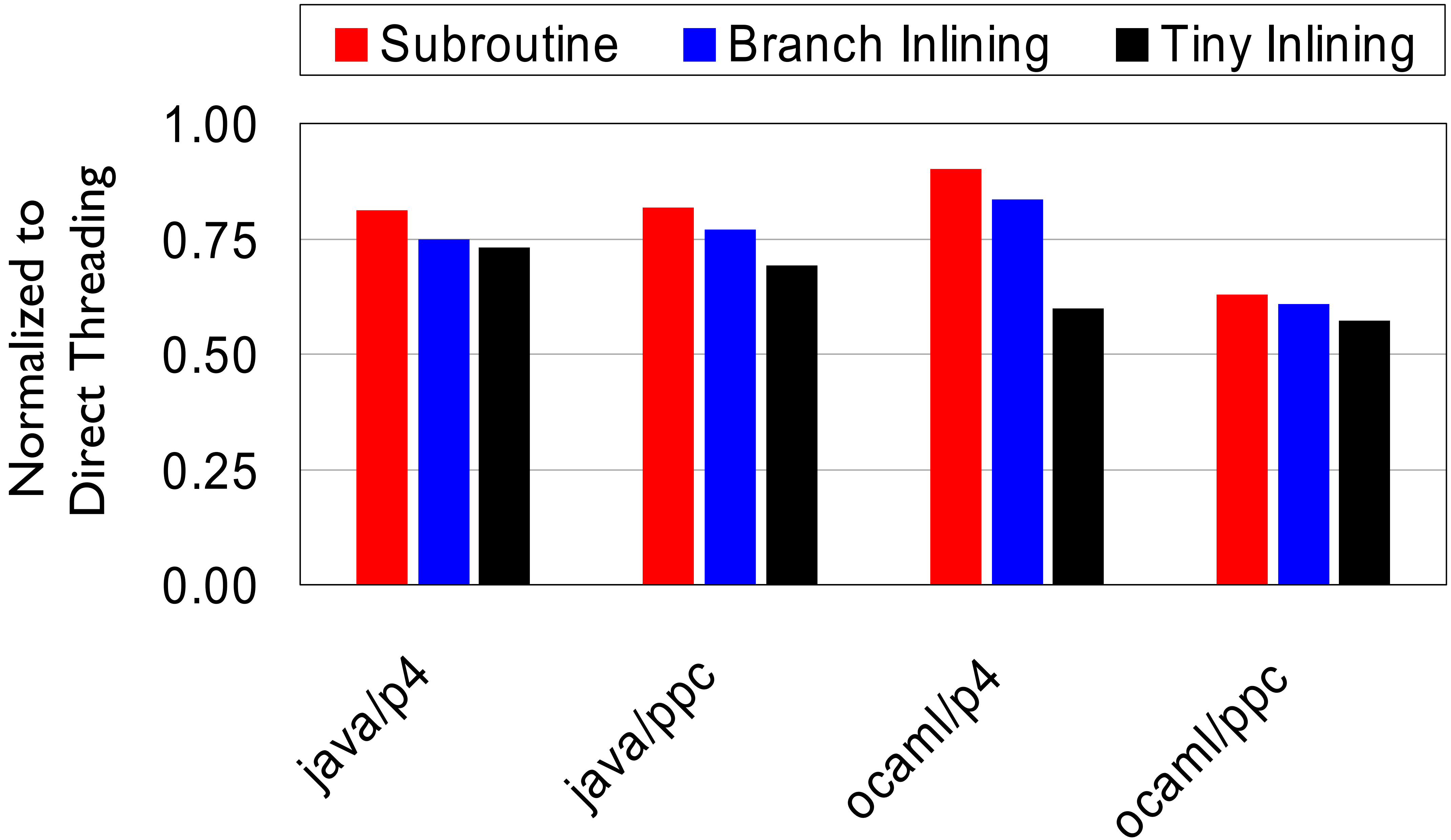
- Package bodies as subroutines and call them

Context Threading (CT) -- Generating specialized code in CTT



- Specialized bodies can also be generated in CTT!

CT Performance



- CT is an efficient interpretation technique

Overview

- ✓ Introduction
- ✓ Background: Interpretation & traces
- ✓ Efficient Interpretation
- Our Approach to Mixed-Mode Execution
  - Selecting Regions
  - Results and Discussion

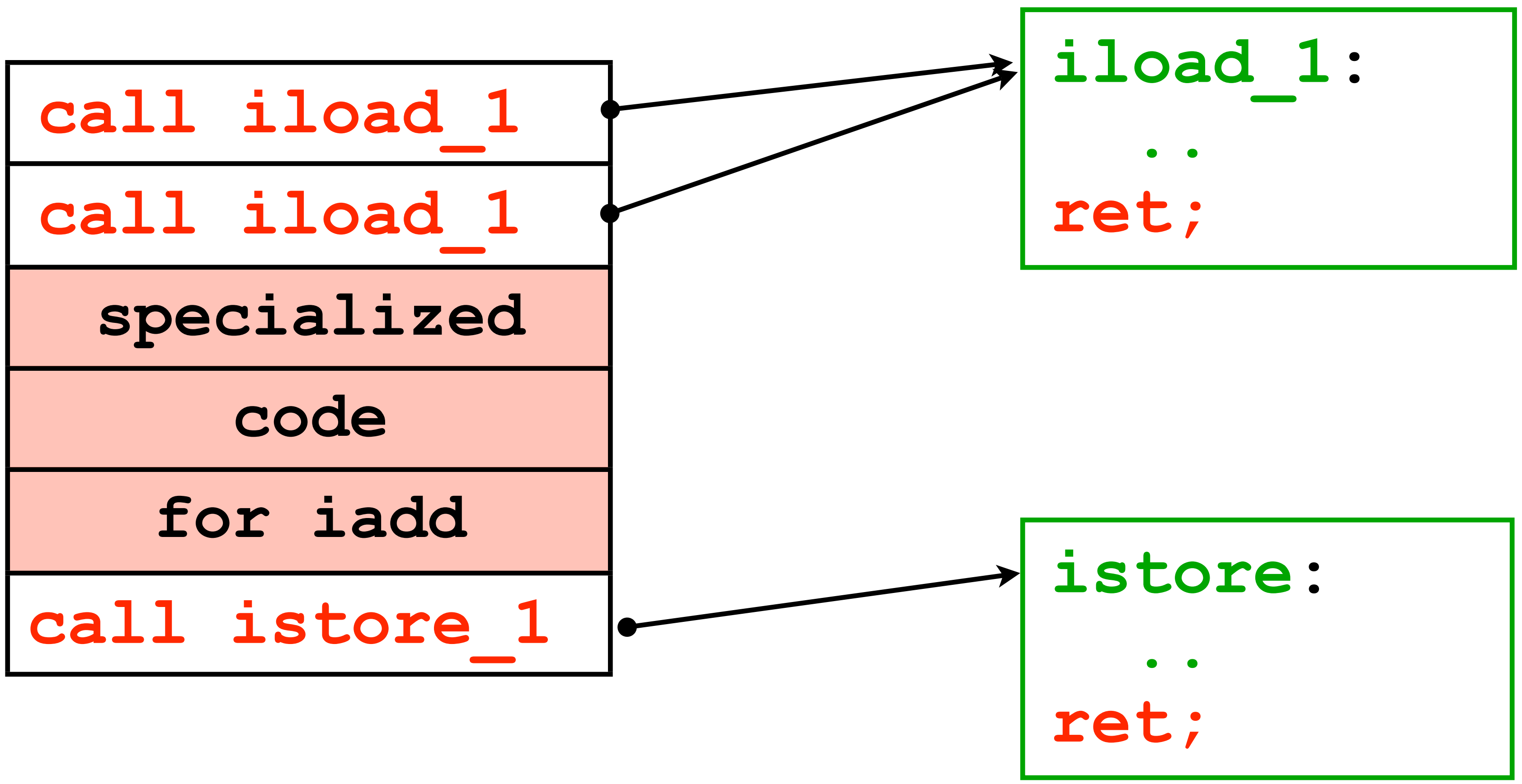
Gradually Extensible Trace Interpreter

Three main enablers:

1. Bodies organized as callable routines so executable regions can efficiently mix compiled code and dispatched bodies.
2. The DTT can point to variously shaped execution units.
3. Efficient, flexible instrumentation.

1. Bodies are callable

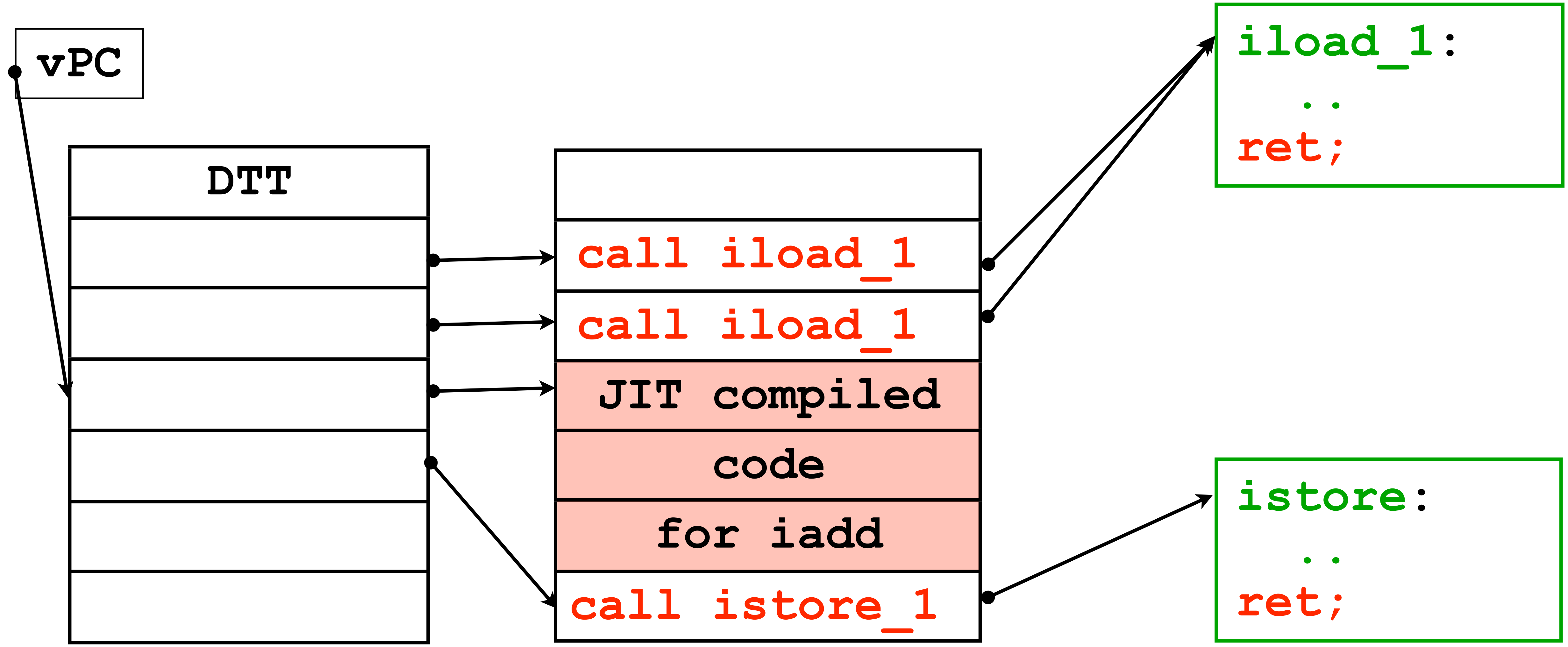
Packaging bytecode bodies as lightweight subroutines means that they can be efficiently called from generated code



- Needn't build all virtual instructions all in one shot.

2. DTT always points to implementation

..of corresponding execution unit

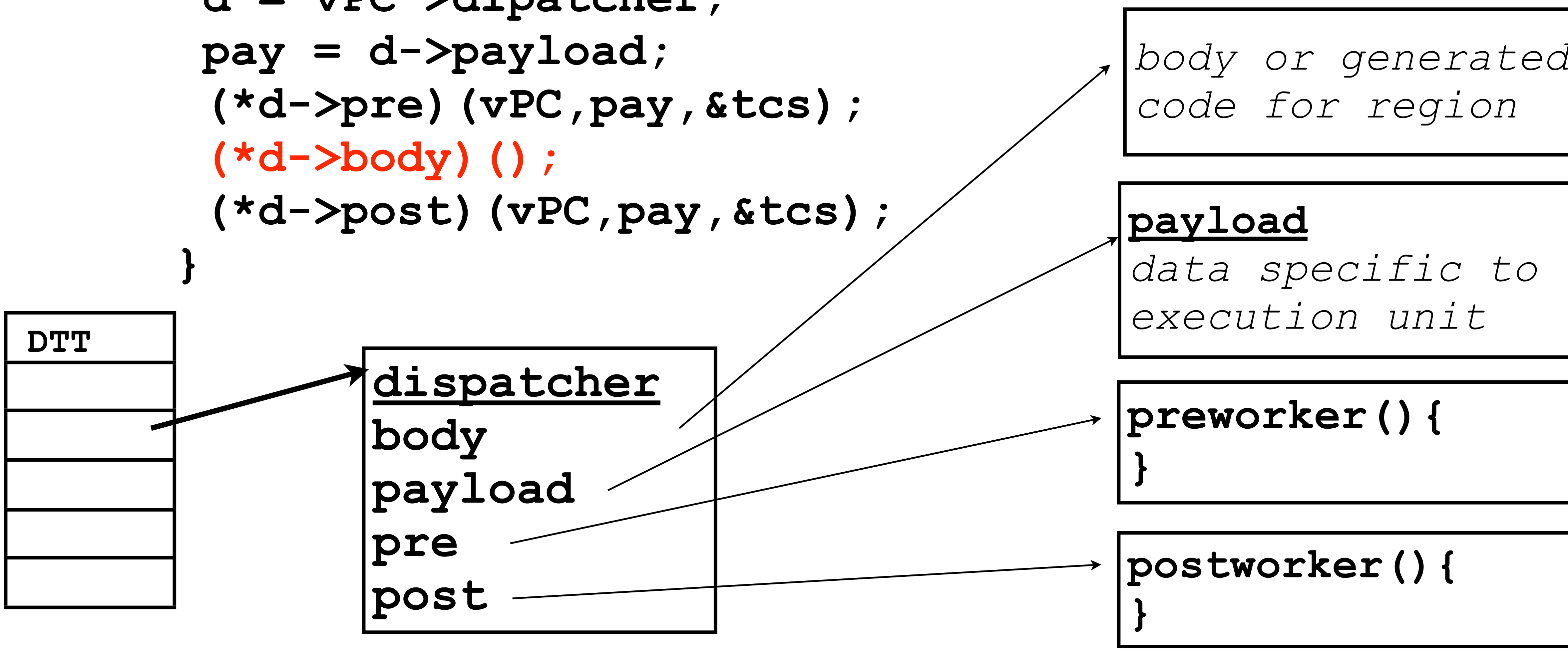


- DTT indirection enables *any* shape of execution unit to be dispatched.

3. Flexible, Efficient Instrumentation

A *dispatcher* describes an execution unit

```
while(1){ //dispatch loop
    d = vPC->dipatcher;
    pay = d->payload;
    (*d->pre)(vPC,pay,&tcs);
    (*d->body)();
    (*d->post)(vPC,pay,&tcs);
  }
```



- Our runtime active before and after each dispatch

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    - Basic Blocks
    - Traces
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Basic Block Detection

Java Source

```
int f(boolean parm){
  if (parm){
    return 42;
  }else{
    return 0;
    }
 }
```

Java Bytecode

```
int f(boolean);
  Code:
    0: iload_1
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```

Basic Block Detection

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while(1){ //dispatch loop
   d = vPC->dipatcher;
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   (*d->pre)(vPC,pay,&tcs);
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```

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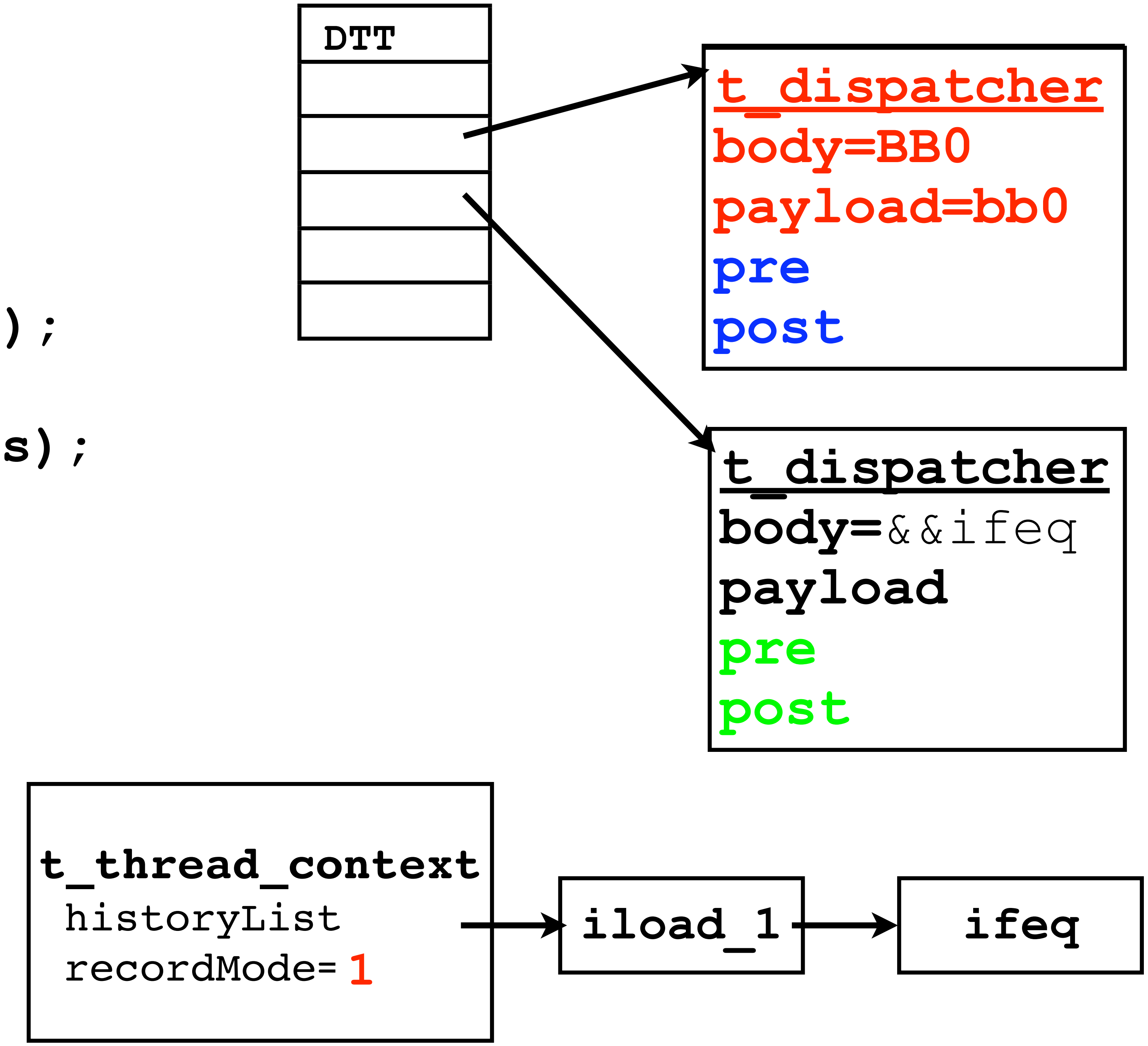
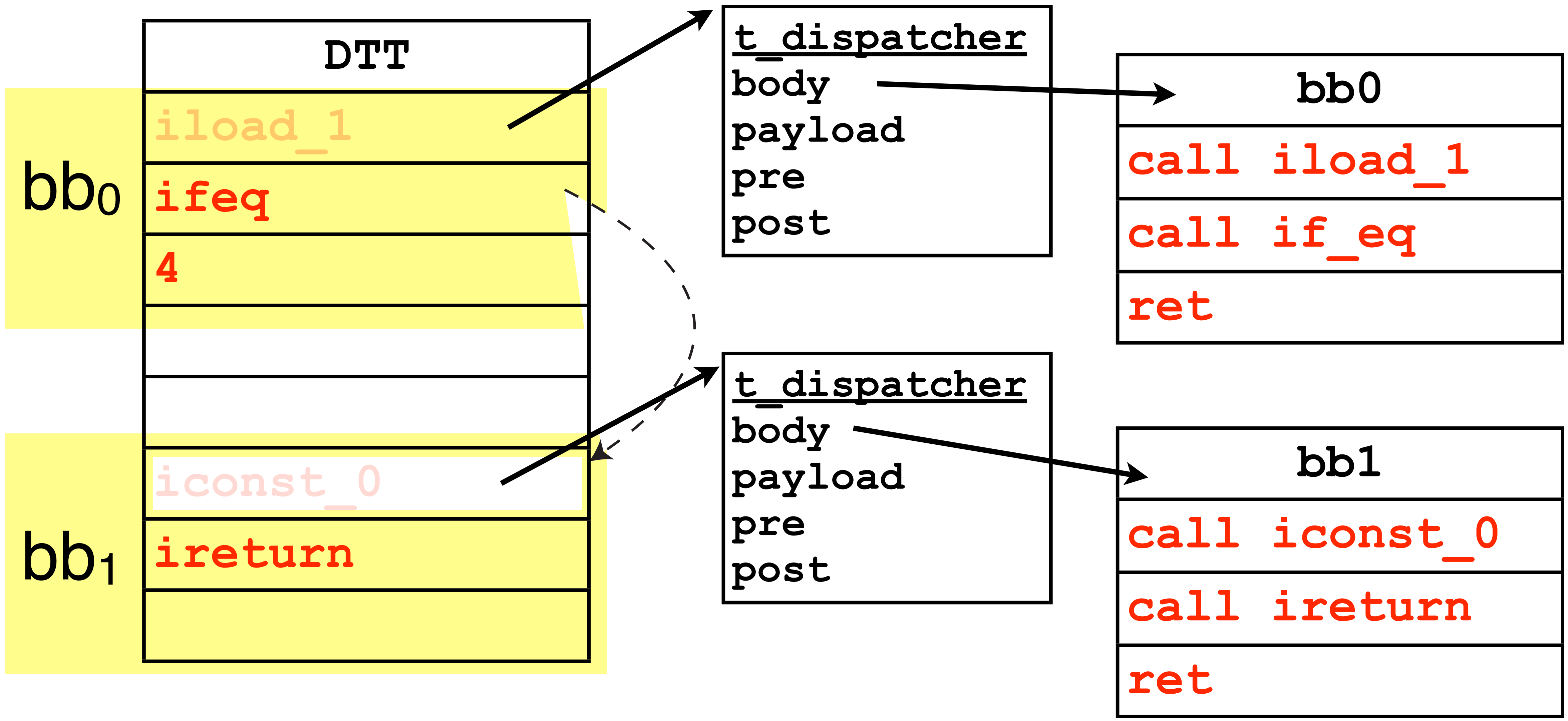


Generated code for a basic block

- Could JIT the bb, currently we generate "subroutine threading style" code for it.



- Basic block is a run-time superinstruction

C Code for interp function

- all in one C function
- thread private are C local variables
- loader initializes DTT to static dispatchers
- dispatch loop calls instrumentation specific to dispatcher

```
static t_dispatcher init[256]={};
interp(t_dispatcher *dtt){
 t_dispatcher *vPC = dtt;

 t_thread_context tcs;
 iload:
   //real work of iload here..
   vPC++;  //to next instruction
   asm volatile("ret");
 iadd: //and many more bodies

  //dispatch loop
  while(1){
   d = vPC->dispatcher;
   pay = d->payload;
   (*d->pre)(vPC,pay,&tcs);
   (*d->body)();
   (*d->post)(vPC,pay,&tcs);
  }
```

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    - ✓ Basic Blocks
    - ▸ Traces
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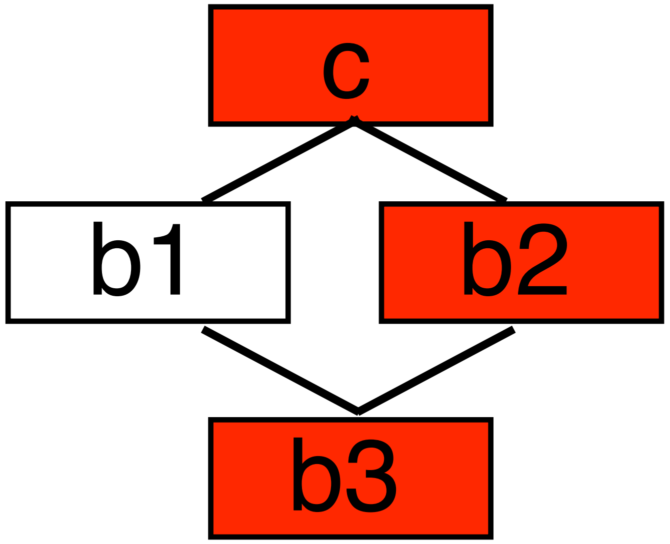
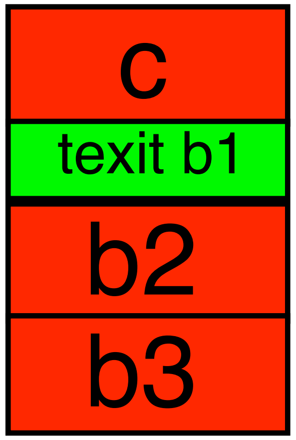
Detecting Traces

- Use Dynamo’s trace detection heuristic.
- Instrument reverse branches until they are hot.
  - Postworker of basic block dispatcher
- Trace generate starting from hot reverse branch:
  - Much like bb’s were recorded
  - Postworker of each basic block region adds each *bb* to thread private history list.
  - Eventually creates new trace dispatcher
  - Hold off generating code until after trace has “trained” a few times..

Trace with if-then-else

```
//c => b2
if (c)
    b1;
else
    b2;
b3;
```

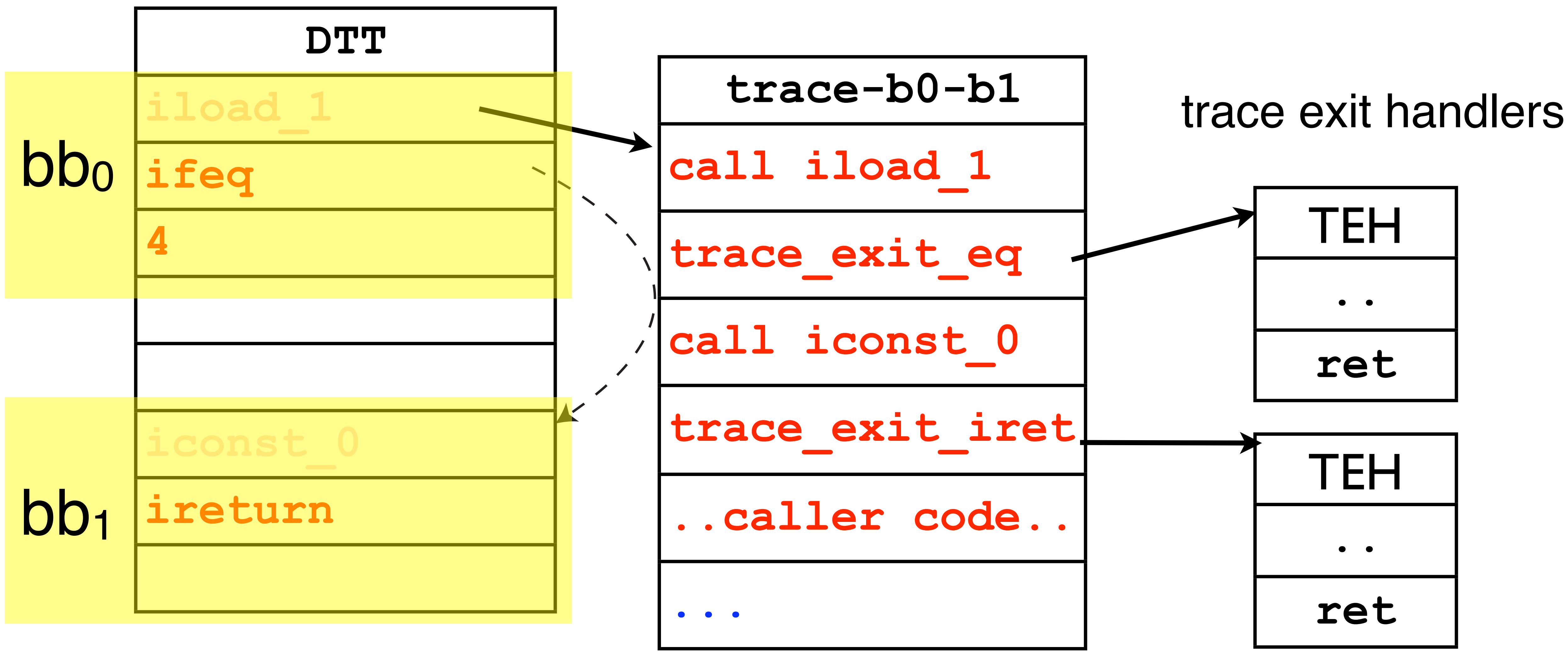




- Trace is path followed by program
- Conditional branches become *trace exits*.
- Do *not* expect trace exits to be taken.

Subroutine threading style code for a Trace

- Dispatch virtual instructions for trace



- Trace is super-super instruction

Trace Exits

```
    trace-b0-b1
    call iload_1
(a) trace_exit_eq
    call iconst_0
(b) trace_exit_iret
    ...
```

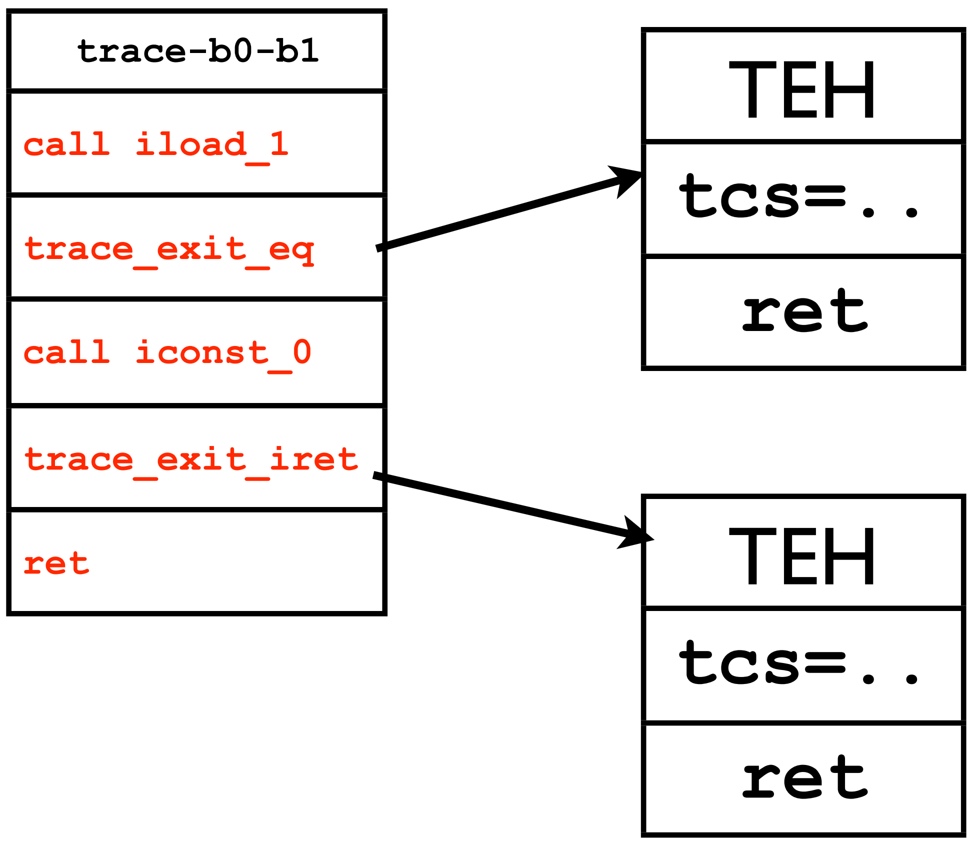
(a) Two-way: from conditional branches

- one leg on trace
- other leg off trace

(b) Multiway: from invokes and returns

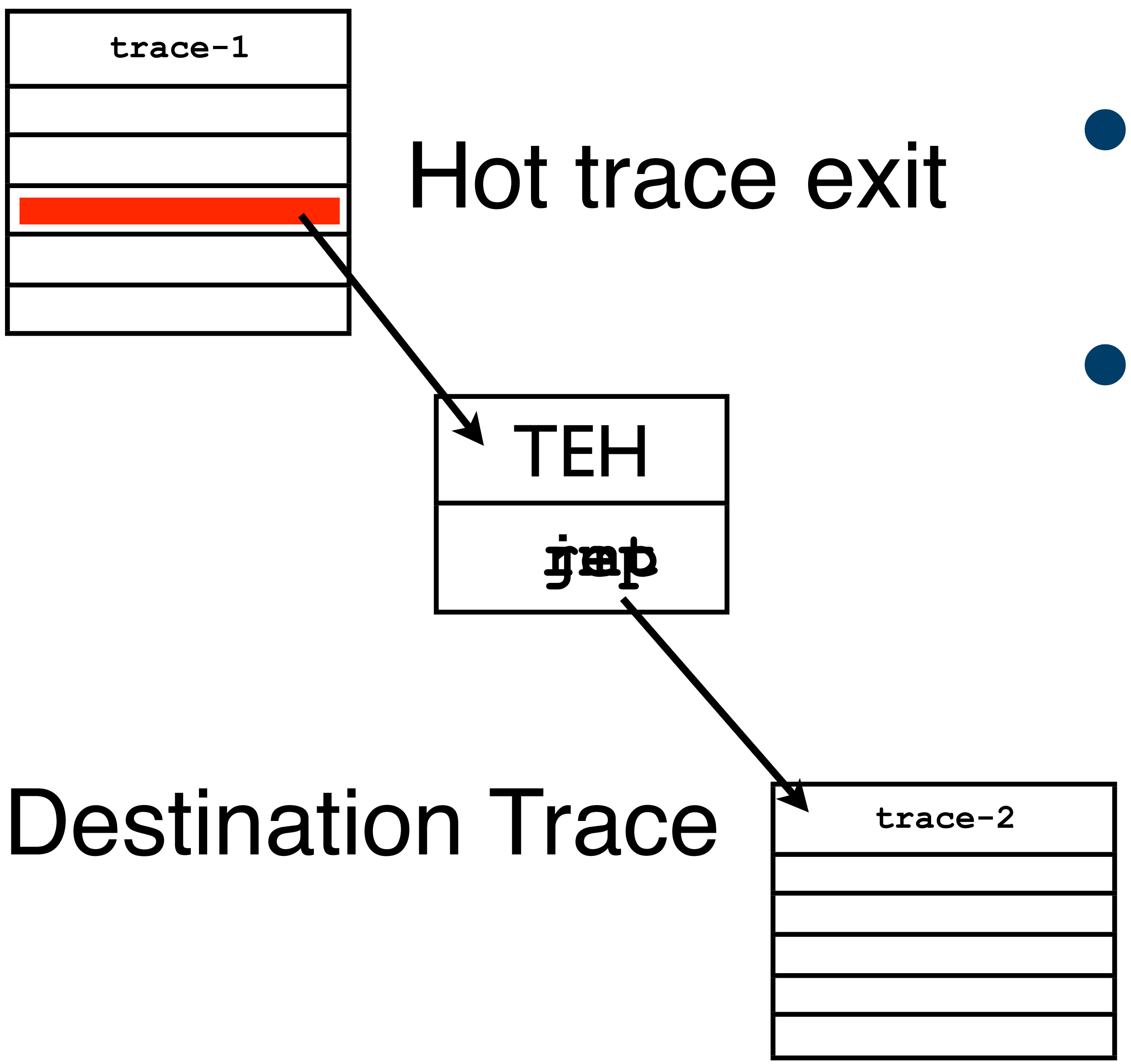
- one leg on trace
- potentially many legs off trace

Trace Exit Handlers



- Code runs when trace exit is taken before return to interpreter
- Record which trace exit has occurred in thread context
- Return to dispatch loop
- Housekeeping roles:
  - flush state of JIT code
  - Trace linking

Trace linking



- When trace exit is hot and destination is a trace
- Rewrite ret at end of trace exit handler as jmp to destination trace
  - Only use of code rewriting in system

Trace JIT

- Generate native code for trace exits
  - A lot like branch inlining from CT system.
- Optimize invokevirtual when call and return occur in same trace.
- Naive register allocation scheme
- Only handle 50 integer/object virtual instructions
  - Do virtual instructions one-by-one
    - Relatively easy debugging
- Floating point should be easy.

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  - Data
  - Discussion
  - Remaining Work in this dissertation

Implementation

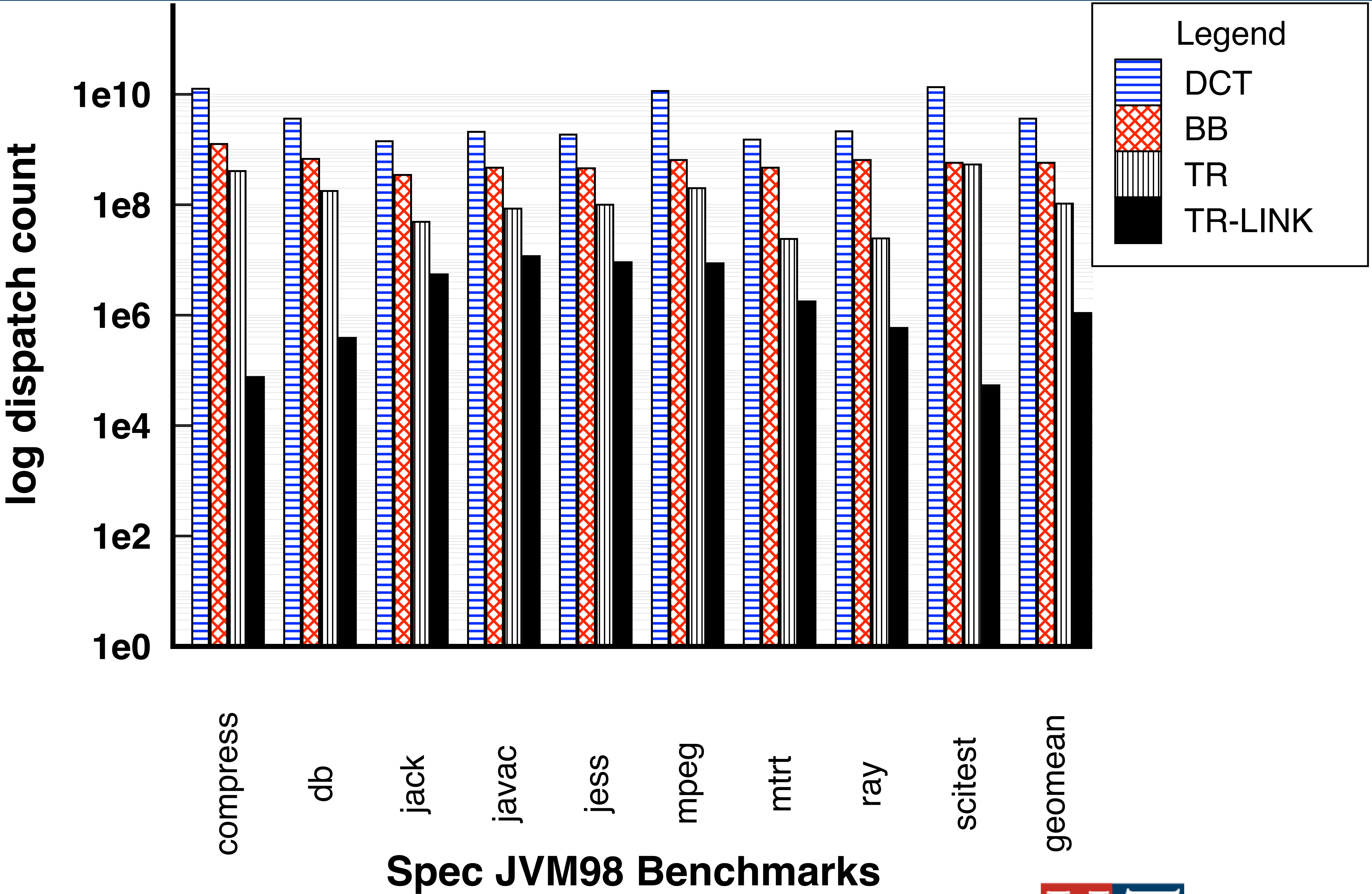
- Modify JamVM 1.1.3 to be SUB threaded
- Gradually extend it to:
  - Detect, execute subroutine style basic blocks
  - Detect, execute subroutine style traces
  - Link traces
  - Compile traces.

Region Shape

- As execution units become larger
- Trips around dispatch loop become less frequent
- Next show data to justify “step back” approach.
- Very simple experiment:
  - Modify dispatch loops to count iterations.

Condition	Description
DCT	Direct Call Threading
BB	CT-style Basic Blocks
TR	Traces (no link, no JIT)
TR-LINK	Linked Traces (no JIT)

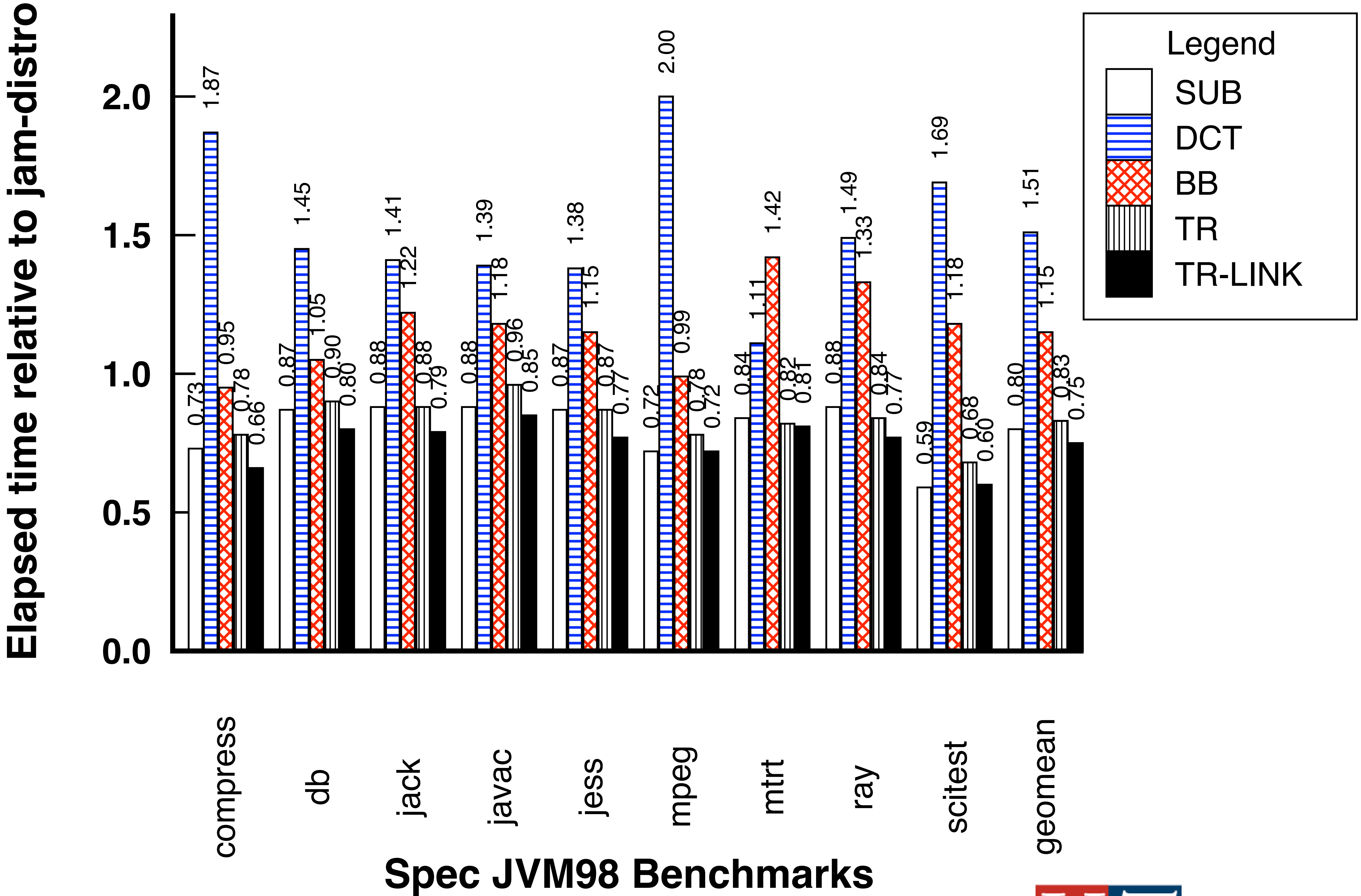
Region Shape Effect on Dispatch Count



How efficient is profiling system?

- Run instrumentation without the JIT.
- Are the intermediate versions of Java viable?
- Include SUB threading in comparison:
  - Since it is an efficient dispatch technique.
- Report elapsed time relative to distro of JamVM

Profiling/Instrumentation Overhead

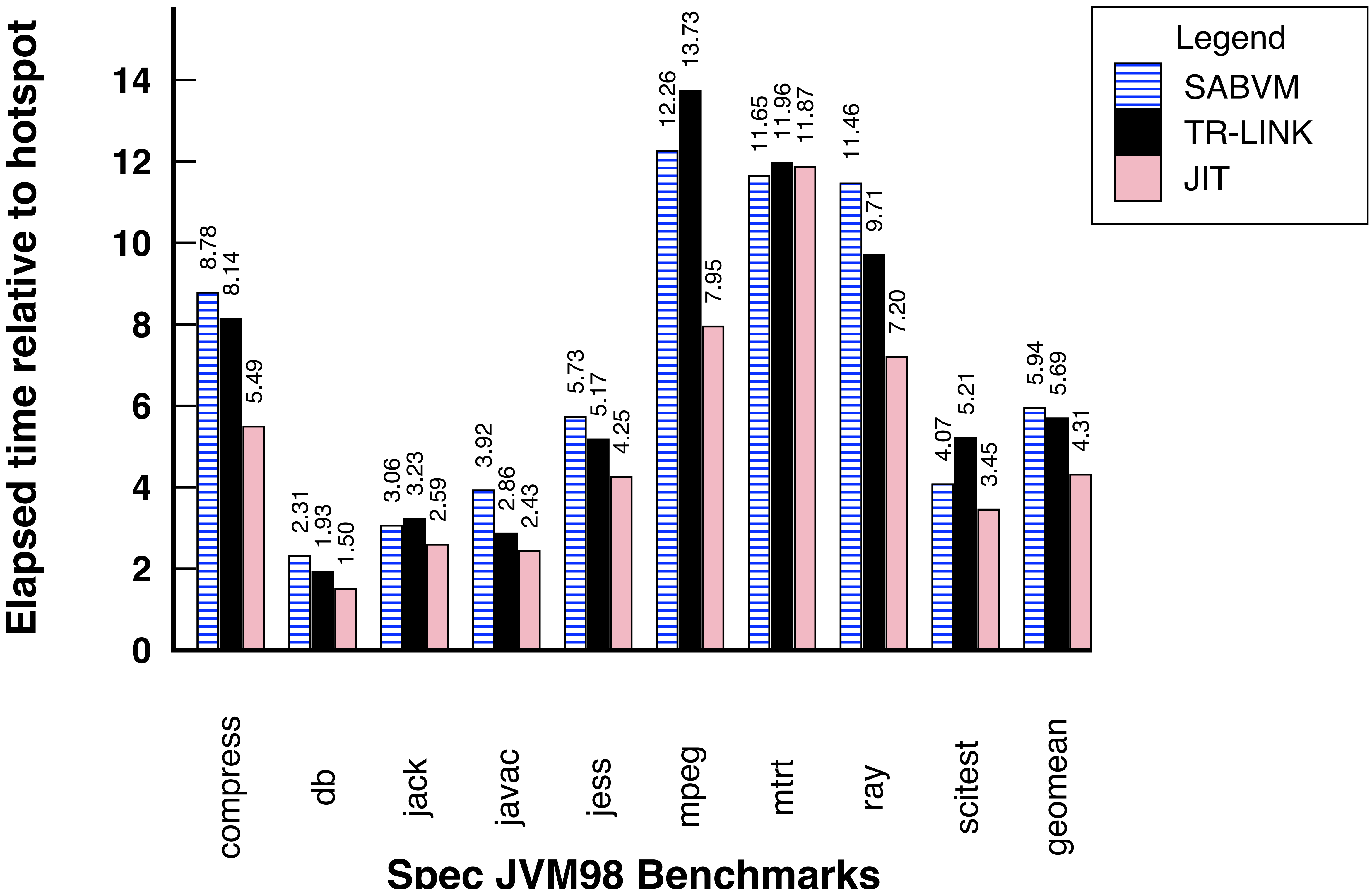


Performance of simple JIT

- Compare YETI performance WITHOUT JIT to selective inlining SableV
- Compare YETI with preliminary trace based JIT to Sun's Hotspot optimizing compiler
- Not much basis for comparison to Hotpath

Condition	Description
TR-LINK	Linked Traces
SABVM	SableVM selective inlining
JIT	Traces (JIT and Link)

JIT Performance relative to Sun Hotspot



Overview

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  - ✓ Data
  - ▸ Discussion (and future work)
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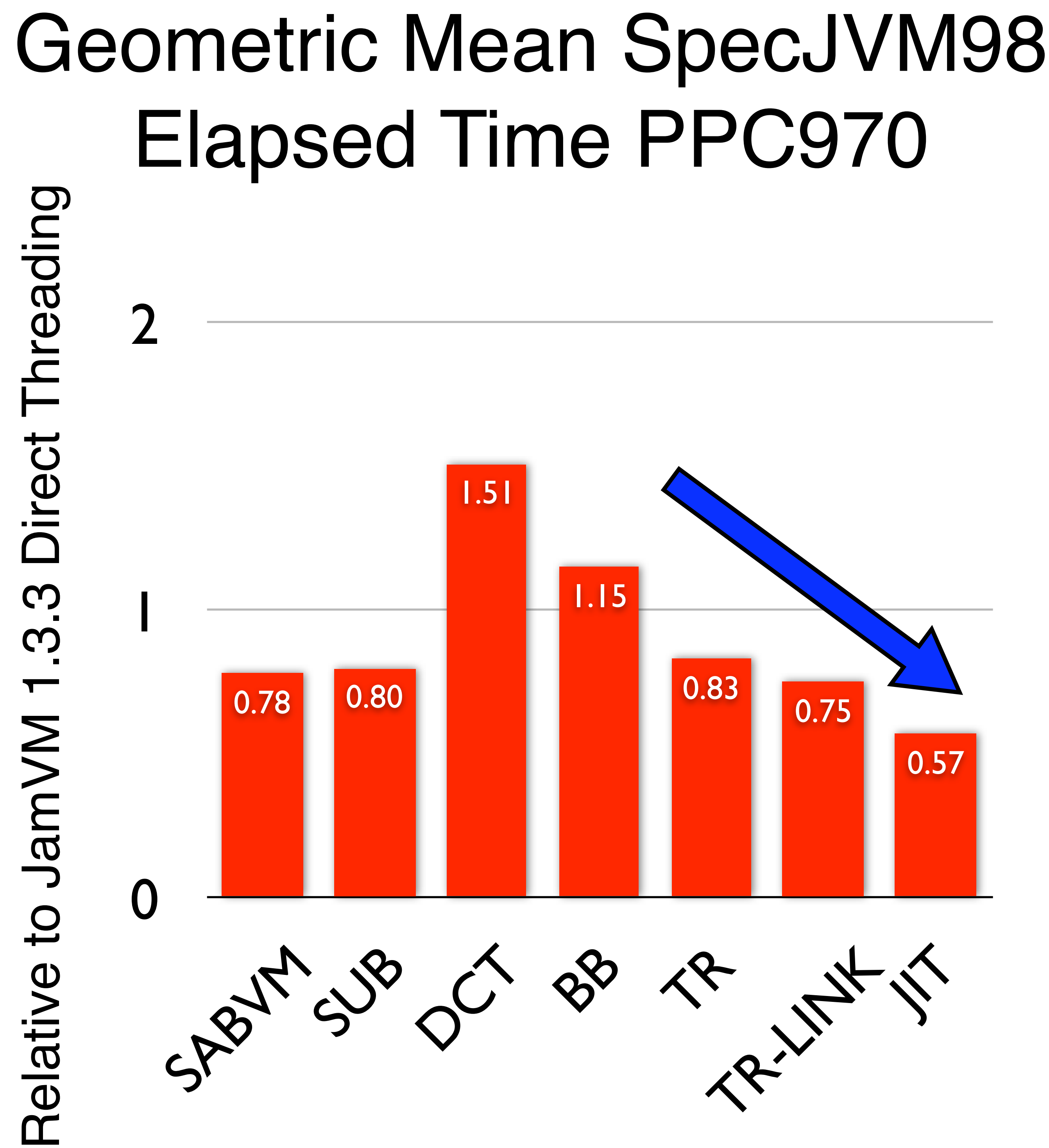
Gradual performance improvement

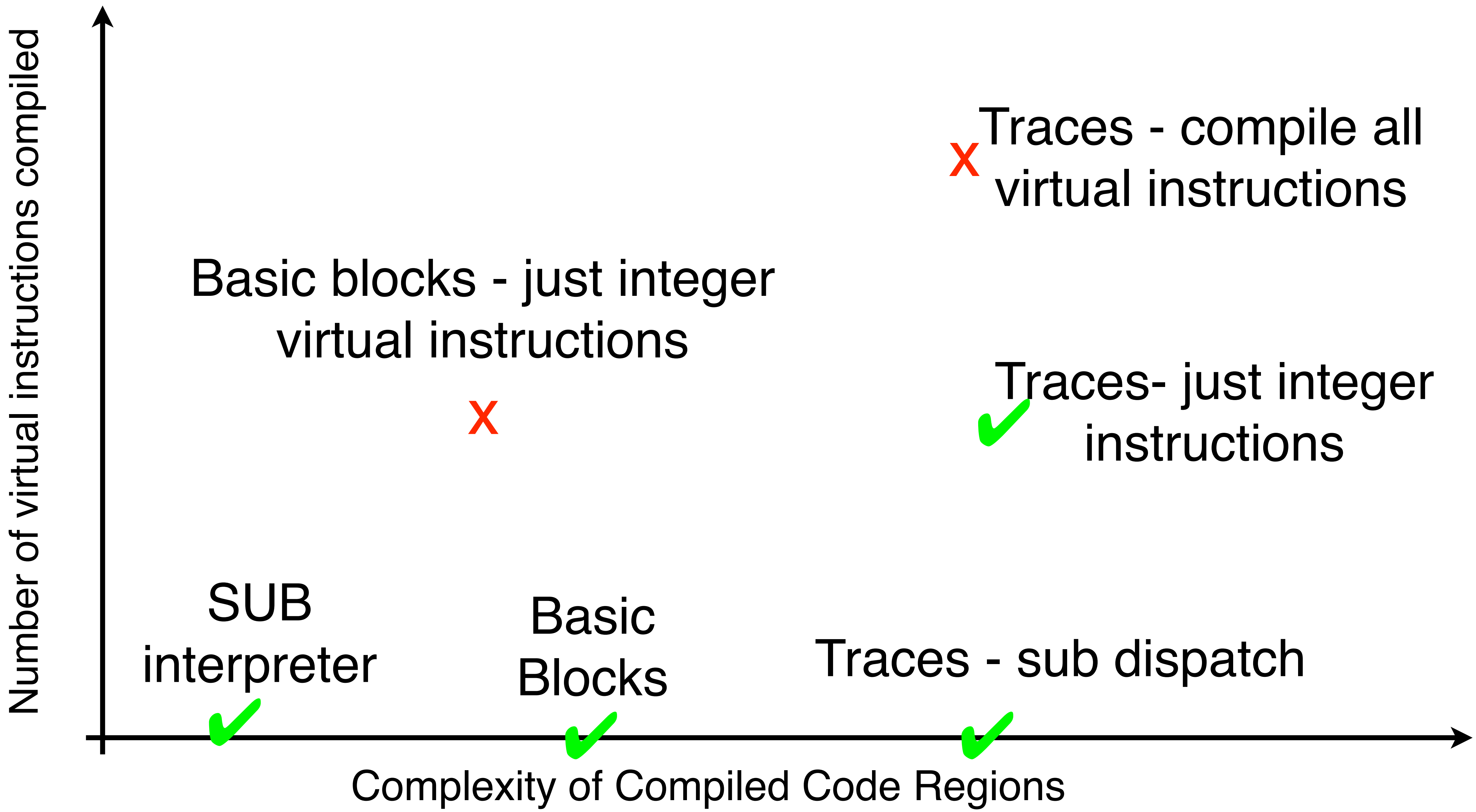
- Performance improves as effort invested.
- SUB very effective for lightweight bodies
- BB not viable by itself
- TR-LINK about same as CT/branch inlining.
- JIT preliminary.



Discussion

- We have demonstrated how to build an interpreter that is simple and yet as efficient as SableVM and JamVM.
- We have shown that our interpreter can be gradually extended to identify, link and compile traces.
- We have shown how generated code can reuse callable virtual instruction bodies.
- Our JIT, although it has no optimizer, only supports 50 Java virtual instructions, improves performance by 24%.
  - More instructions, better performance?

2D vision of Incremental VM lifecycle..



- Have explored this space

Application

- If I had to build a new interpreter.
  - for "lightweight" bodies, so dispatch matters.
- Start with bodies that can be conditionally compiled to be either direct threaded or callable.
- Bring up the system using DCT because the dispatch loop makes it easier to debug.
  - e.g. Logging from dispatch loop is very helpful.
- Primary platforms would run SUB and secondary platforms would run direct threading.
- Gradually extend as described.

Future Work

- Work could go in many different directions.
- Apply to another language system
  - JavaScript? Python? Fortress?
  - Deal with polymorphic bytecodes
- Extend JIT/Optimizer
  - Explore performance potential
  - Need a lot more infrastructure (e.g. IR)
- Package infrastructure for others to apply.

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Proposed Work for winter 2007.

- Infrastructure to measure:
  - Compile time;
  - Proportion of virtual instructions executed from compiled code.
- Add float register class.
  - scimark, ray, Linpack would likely benefit.
- Compile Basic Blocks
  - Long bb benchmarks will benefit.
- Write, write, write.

- Back 12

- Efficient 23
- Our 28
- BB 33
- TR 38
- RES 46
- CONC 54