The Efficient Handling of Guards in the Design of RPython's Tracing JIT

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RPython and PyPy

- Context: RPython
- a language for writing interpreters for dynamic languages
- a generic tracing JIT, applicable to many languages
- used to implement PyPy, an efficient Python interpreter

How fast is PyPy?

Tracing JITs Compile by Observing an Interpreter

- VM contains both an interpreter and the tracing JIT compiler
- JIT works by observing and logging what the interpreter does
- for interesting, commonly executed code paths
- produces a linear list of operations (trace)

Code

```
while j < 100:
    j += 1
    if a is None:
        break
    a = a.f()
```

Frames

a = a_1
j = j_1

Trace

[j_1, a_1]

Code

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while j < 100:
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    a = a.f()
```

Frames

a = a_1
j = j_2

Trace

[j_1, a_1]
j_2 = int_add(j_1, 1)

Guards

- Points of control flow divergence are marked with guards
- Operations that check whether conditions are still true
- When a guard fails, execution of the trace stops and continues in the interpreter

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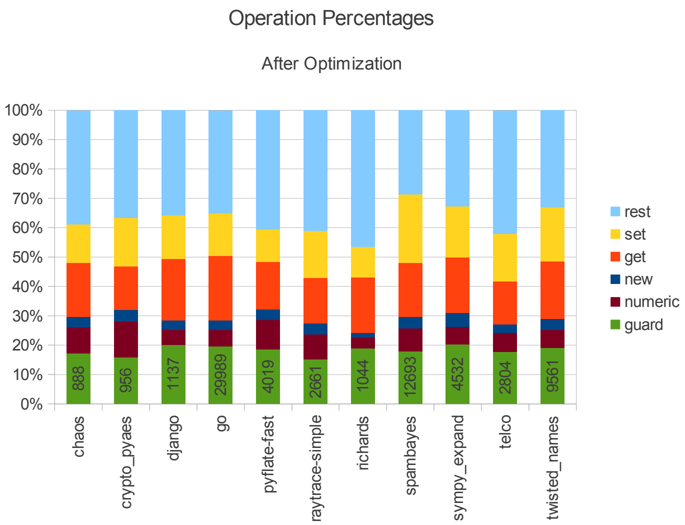
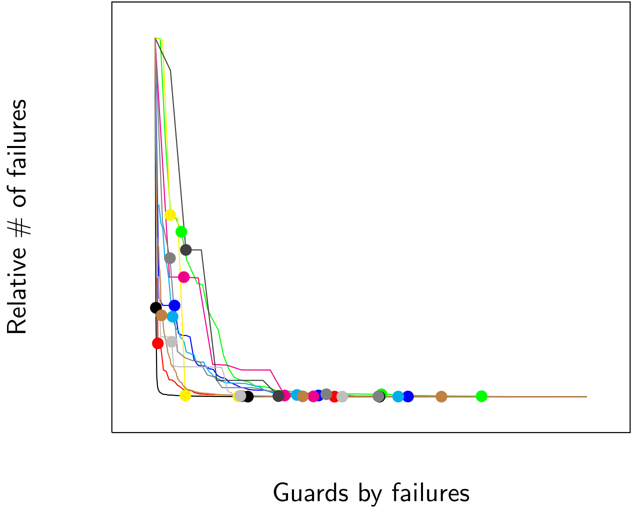
Guard Characteristics

- lots of them, up to 20% guards
- most never fail
- need big information attached to them


Operation Percentages
After Optimization
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
888
956
1137
29989
4019
2661
1044
12693
4532
2804
9561
chaos
crypto_pyaes
django
go
pyflate-fast
raytrace-simple
richards
spambayes
sympy_expand
telco
twisted_names
rest
set
get
new
numeric
guard

Guard Failure Rates / Go Benchmark (29989 Guards)

Guard Failure Rates



Code | Frames | Trace

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a = a_1
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[j_1, a_1]
j_2 = int_add(j_1, 1)
guard_nonnull(a_1)

Inlining

Tracing automatically does (potentially deep) inlining

Code	Frames	Trace

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Code

Frames

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n = self.value >> 2
if n == 1:
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setfield_gc(a_2, descr='value')
b_2 = int_lt(j_2, 100)
guard_true(b_2)
jump(j_2, a_2)

Symbolic Frame Capturing

- Guard can fail deep inside inlined function
- when going back to the interpreter, call stack needs to be re-created
- done with the help of symbolic frame stacks
- these show how trace variables fill the to-be-built interpreter stack frames

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Symbolic Frame Compression

- There are a lot of guards
- Naively storing symbolic frames would be costly in terms of memory
- need to store them compactly
- observation: from one guard to the next, the non-top stack frames don't change
- share these between subsequent guards

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Compact Representation

also need a byte-saving binary representation, but that's just boring work

Interaction with Optimization

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- examples:
  - allocation removal (need to allocate objects before resuming)
  - delayed heap stores (need to do stores before resuming interpreter)
- can be compressed using similar techniques

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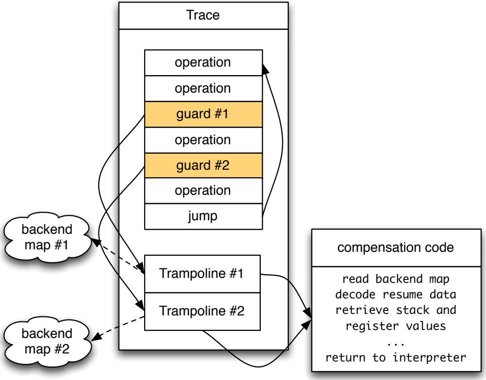
In case of failure

- execution jumps to shared compensation code, decodes and stores mapping
- returns to interpreter that rebuilds state

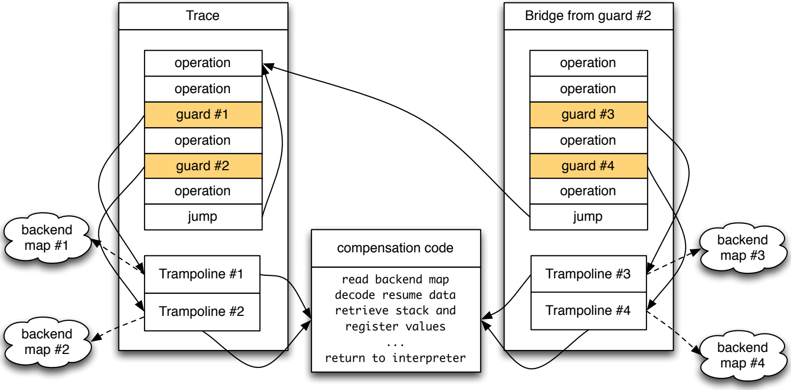
Compiling a Trace



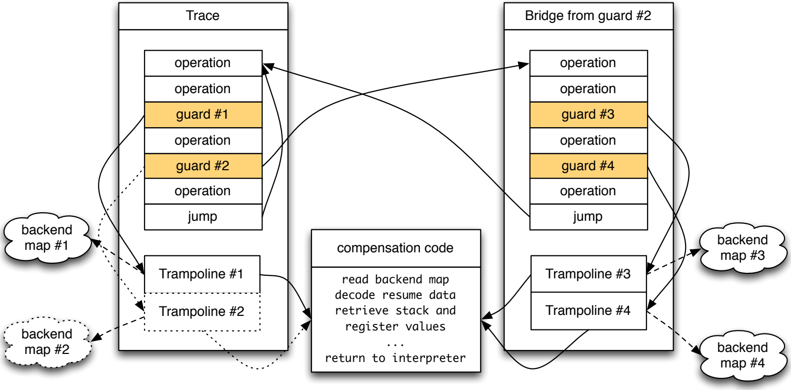
Bridges

- When a trace fails often, it becomes worth to attach a new trace to it
- This is called a bridge
- The bridge is attached by patching the guard machine code
- when this guard fails in the future, the new trace is executed instead

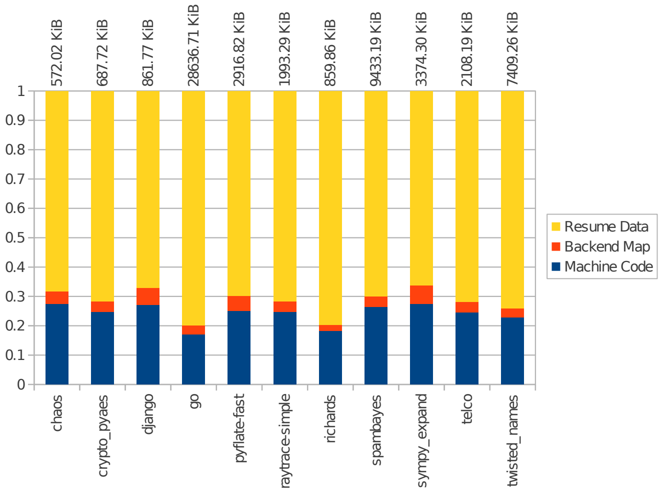
Compiling a Bridge

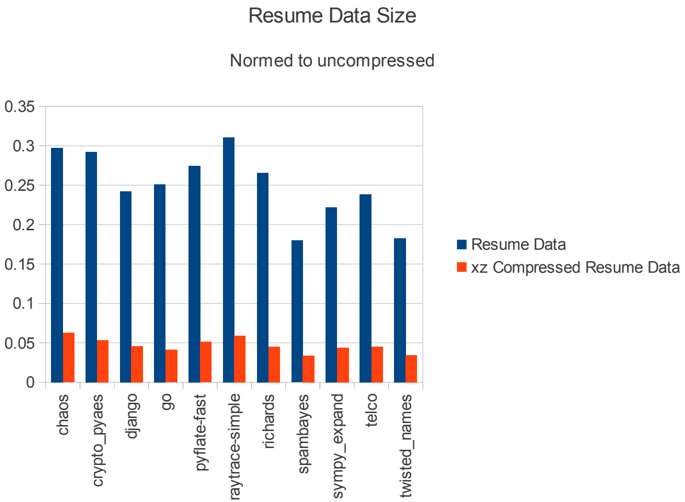


Patching Guards for Bridges



JIT memory overhead




Resume Data Size
Normed to uncompressed
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
chaos
crypto_pyaes
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Resume Data
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- not even any direct performance gains
- keep memory usage sane
- allows good bridges

Thank you! Questions?

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