Master/Slave Speculative Parallelization

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The Basics

- #1: a well-known problem:

  On-chip Communication

- #2: a well-known opportunity:

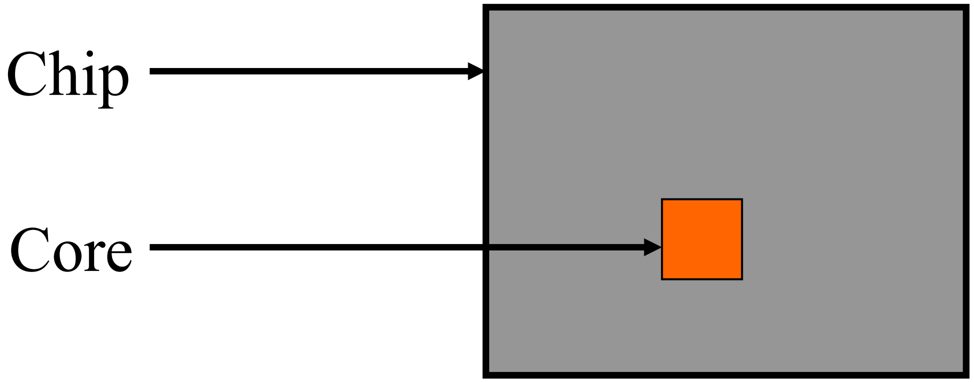
  Program Predictability

- #3: our novel approach to #1 using #2

Problem: Communication

- Cores becoming “communication limited”
  - Rather than “capacity limited”
- Many, many transistors on a chip, but…
- Can’t bring them all to bear on one thread
  - Control/data dependences = freq. communication

Best core << chip size

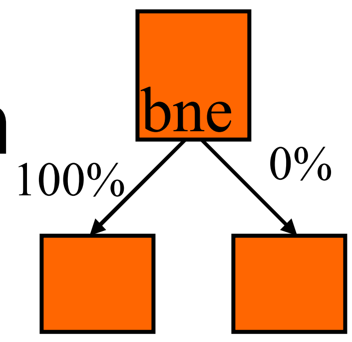


- Sweet spot for core size
  - Further size increases either hurts Mhz or IPC

How can we maximize core's efficiency?

Opportunity: Predictability

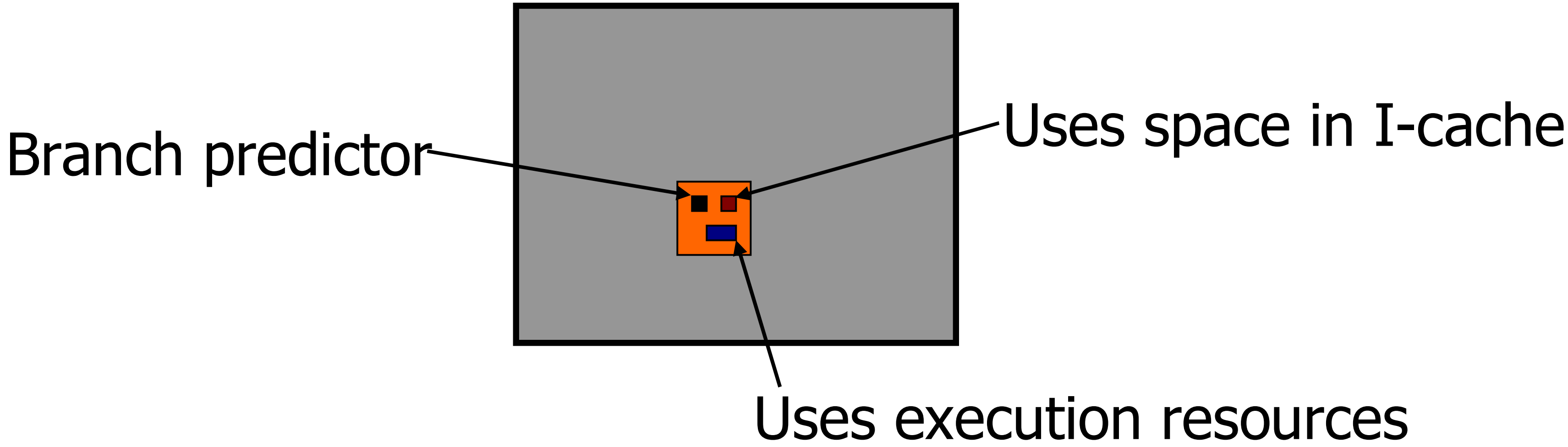
- Many programs behaviors are predictable
  - Control flow, dependences, values, stalls, etc.
- Widely exploited by processors/compilers
  - But, not to help increase effective core size
  - Core resources used to make, validate pred's
- Example: perfectly-biased branch



Speculative Execution

- Execute code before/after branch in parallel
- Branch is fetched, predicted, executed, retired

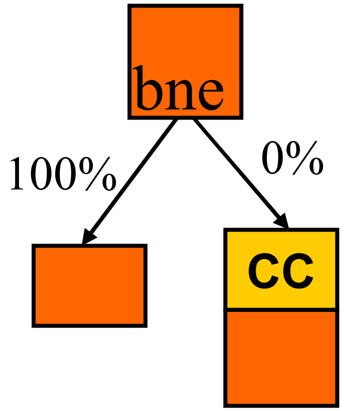
All of this occurs in the core



Not just the branch, but its backwards slice

Trace/Superblock Formation

- Optimize code assuming the predicted path
  - Reduces cost of branch and surrounding code
  - Prediction implicitly encoded in executable



- Code still verifies prediction
  - Branch & slice still fetched, executed, committed, etc.

All of this occurs on the core

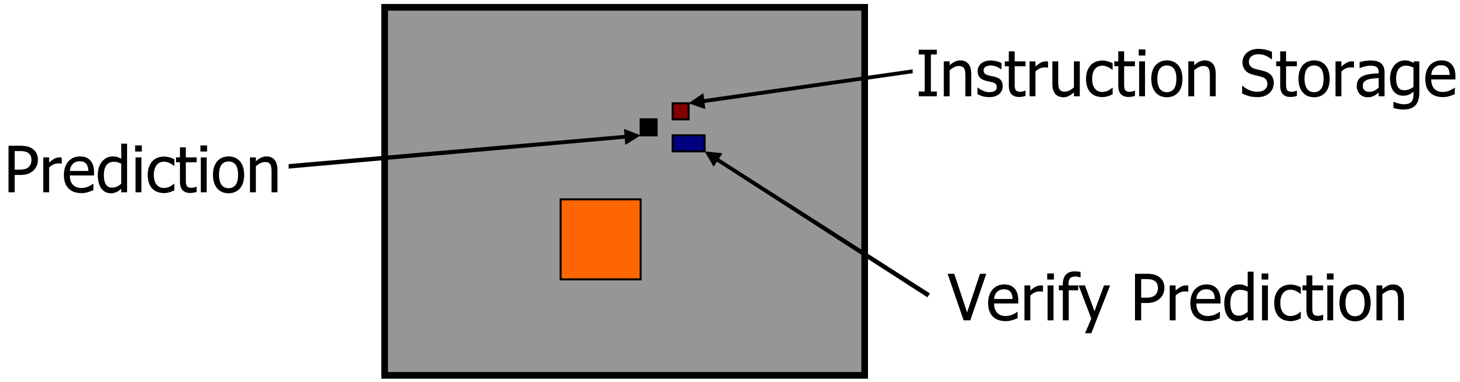
Why waste core resources?

- The branch is perfectly predictable!

The core should only execute instructions that are not statically predictable!

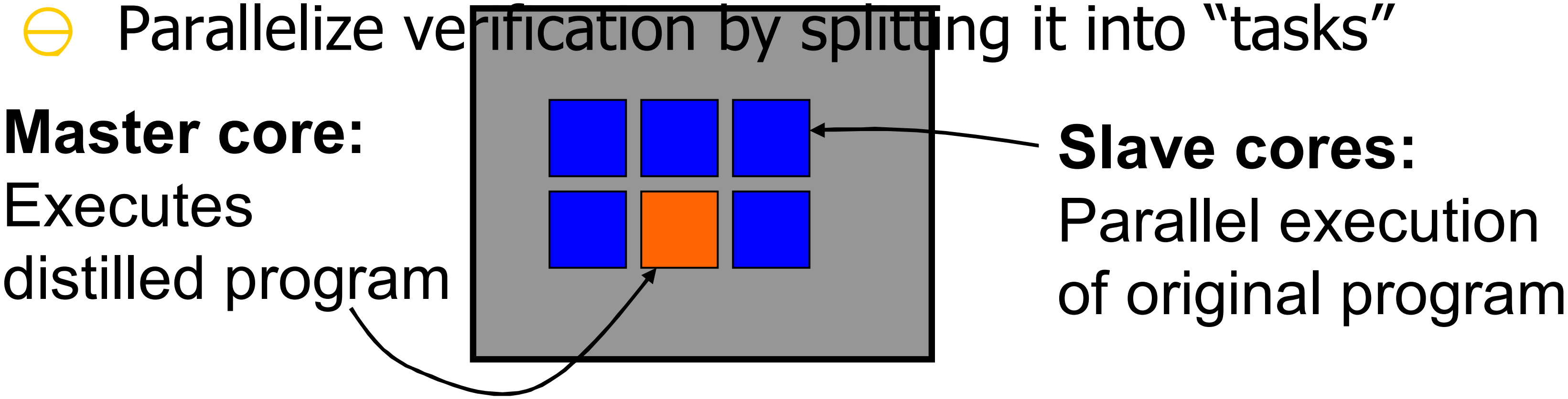
If not in the core, where?

- Anywhere else on chip!
- Because it is predictable:
  - Doesn't prevent forward progress
  - We can tolerate latency to verify prediction



A concrete example: Master/Slave Speculative Parallelization

- Execute "distilled program" on one processor
  - A version of program with predictable inst's removed
  - Faster than original, but not guaranteed to be correct
- Verify predictions by executing original program
  - Parallelize verification by splitting it into "tasks"

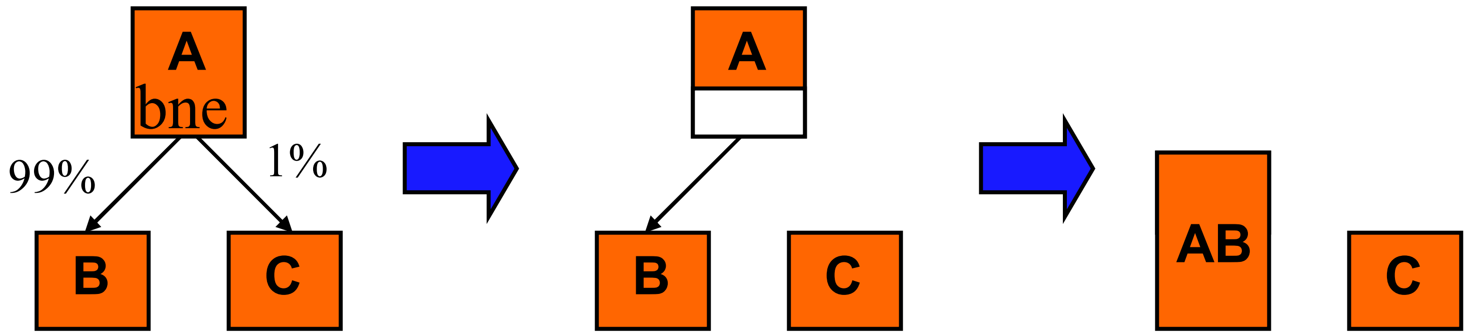


Talk Outline

- Removing predictability from programs
  - “Approximation”
- Externally verifying distilled programs
  - Master/Slave Speculative Parallelization (MSSP)
- Results Summary
- Summary

Approximation Transformations

- Pretend you've proven the common case
  - Preserve correctness in the common case
  - Break correctness in uncommon case
    - Use profile to know the common case



Not just for branches

- Values:

  Load is highly invariant (usually gets 7)

  ~~ld r13, 0(X)~~ addi $zero, 7, r13

- Memory Dependences:

  st r12, 0(A)

  ~~ld r11, 0(B)~~

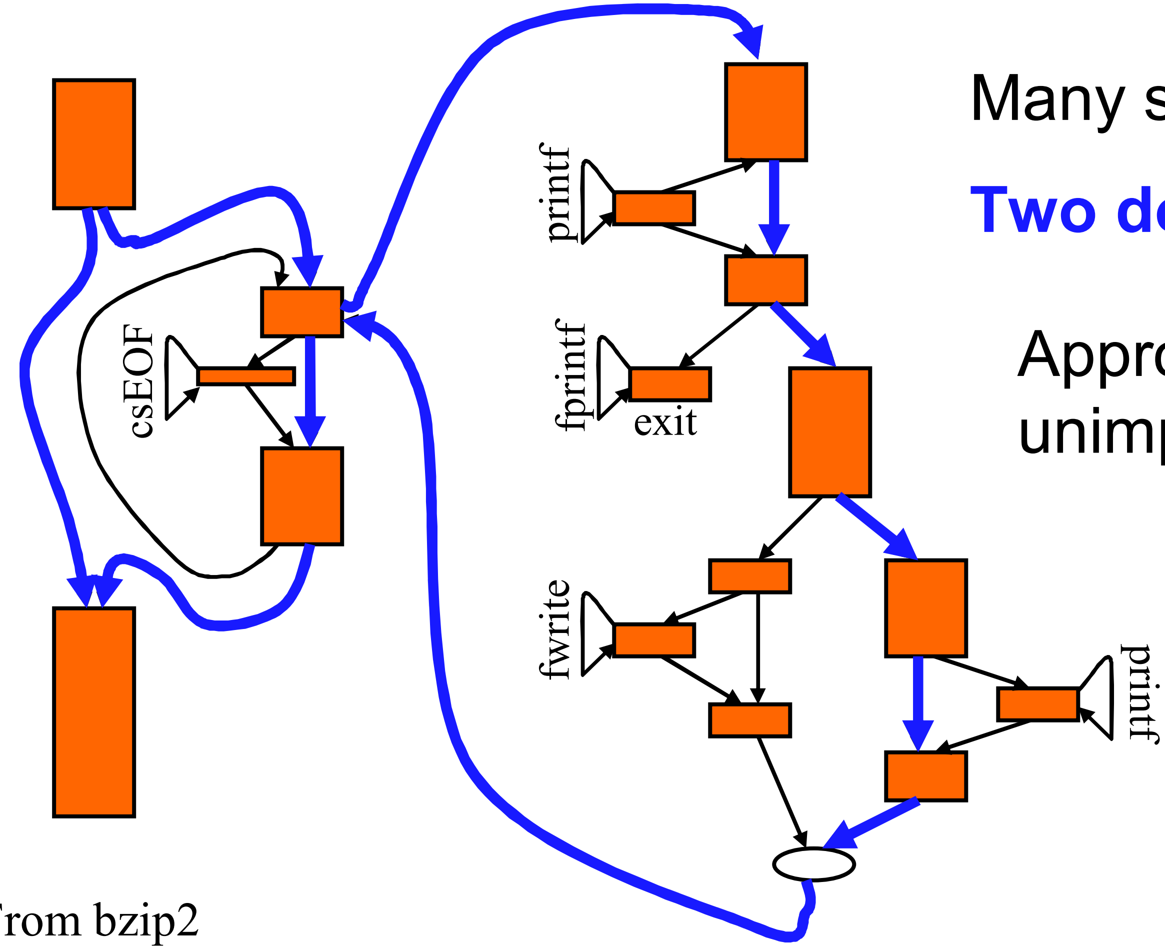
  mv r12, r11

  A and B ~~may~~ never / always alias

  If rarely alias in practice?

  If almost always alias?

Enables Traditional Optimizations



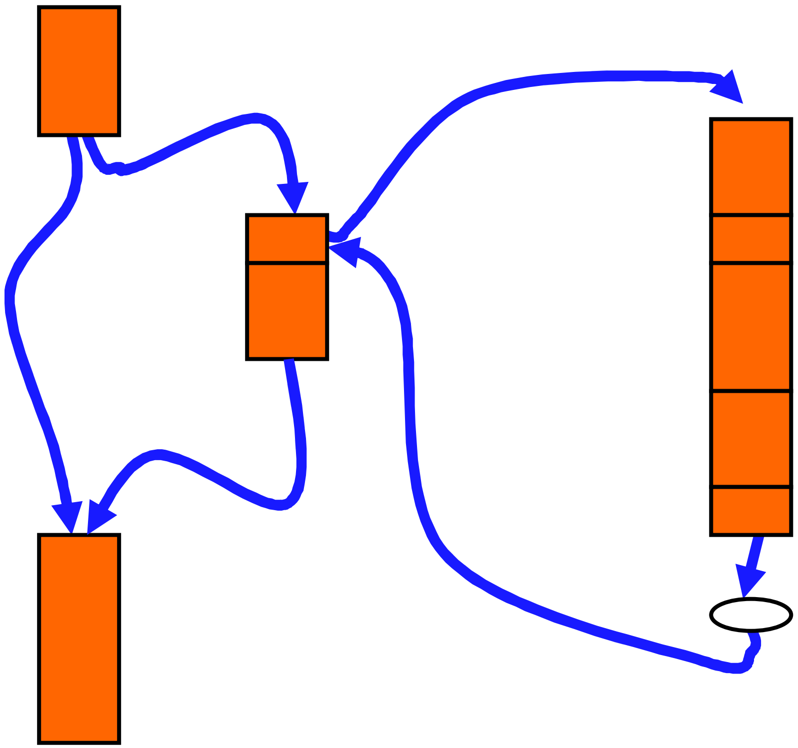
Many static paths

Two dominant paths

Approximate away unimportant paths

From bzip2

Enables Traditional Optimizations



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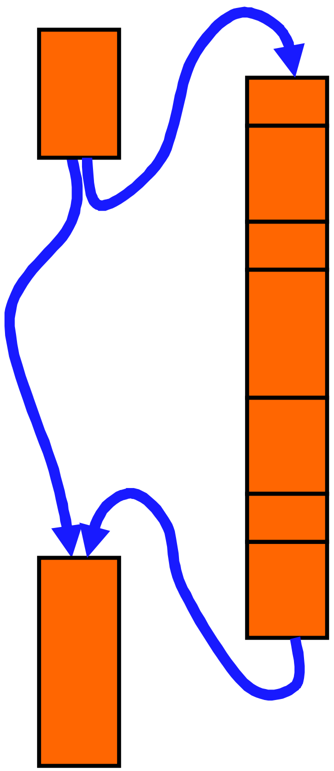

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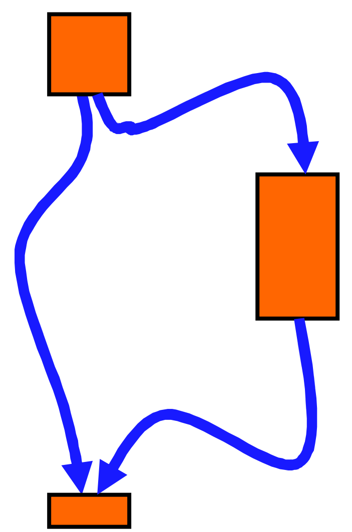
Approximate away unimportant paths

Very straightforward structure

Easy for compiler to optimize

Enables Traditional Optimizations



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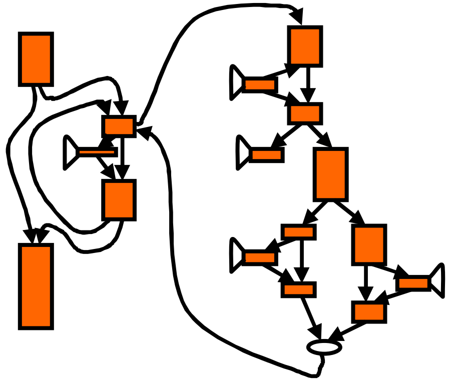
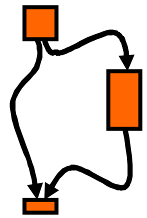
Effect of Approximation

Original Code



Distilled Code



- Equivalent 99.999% of the time, better execution characteristics
  - Fewer dynamic instructions: ~1/3 of original code
  - Smaller static size: ~2/5 of original code
  - Fewer taken branches: ~1/4 of original code
  - Smaller fraction of loads/stores
- Shorter than best non-speculative code
  - Removing checks: code incorrect .001% of the time

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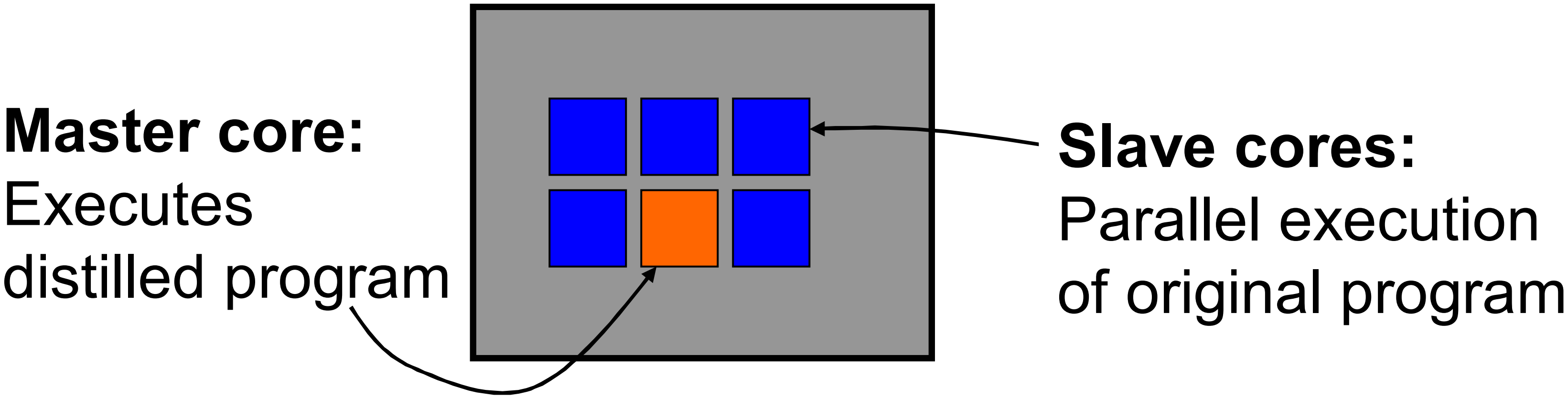
Goal

- Achieve performance of distilled program
- Retain correctness of original program

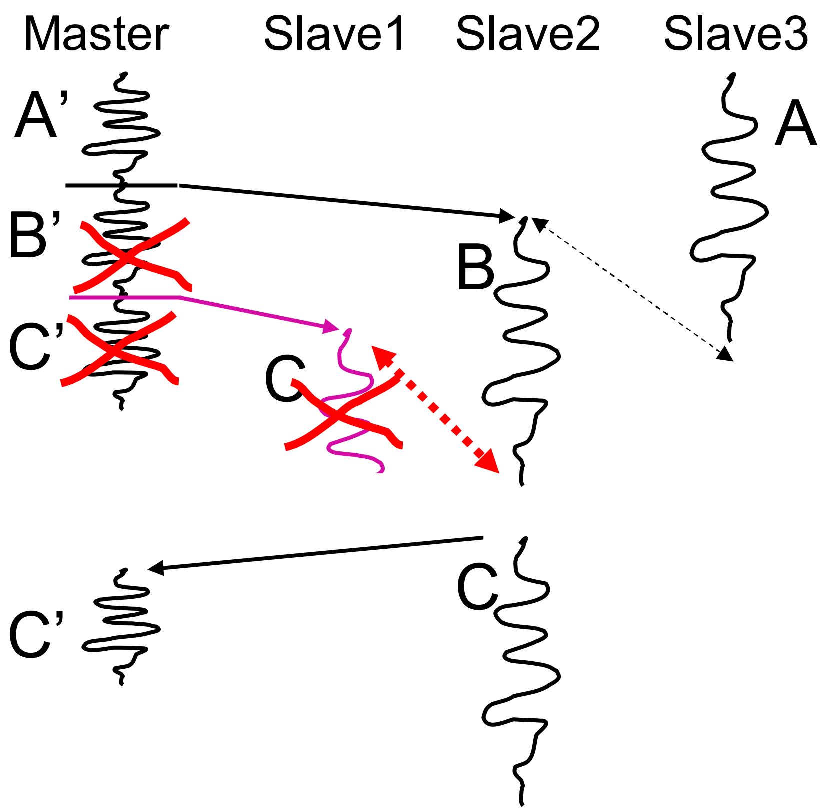
- Approach:
  - Use distilled code to speed original program

Checkpoint parallelization

- Cut original program into “tasks”
  - Assign tasks to processors
- Provide each a checkpoint of registers & memory
  - Completely decouples task execution
  - Tasks retrieve all live-ins from checkpoint
- Checkpoints taken from distilled program
  - Captured in hardware
  - Stored as a “diff” from architected state


Master core:
Executes
distilled program
Slave cores:
Parallel execution
of original program

Example Execution



Start Master and Slave from architected state

Take checkpoint, use to start next task

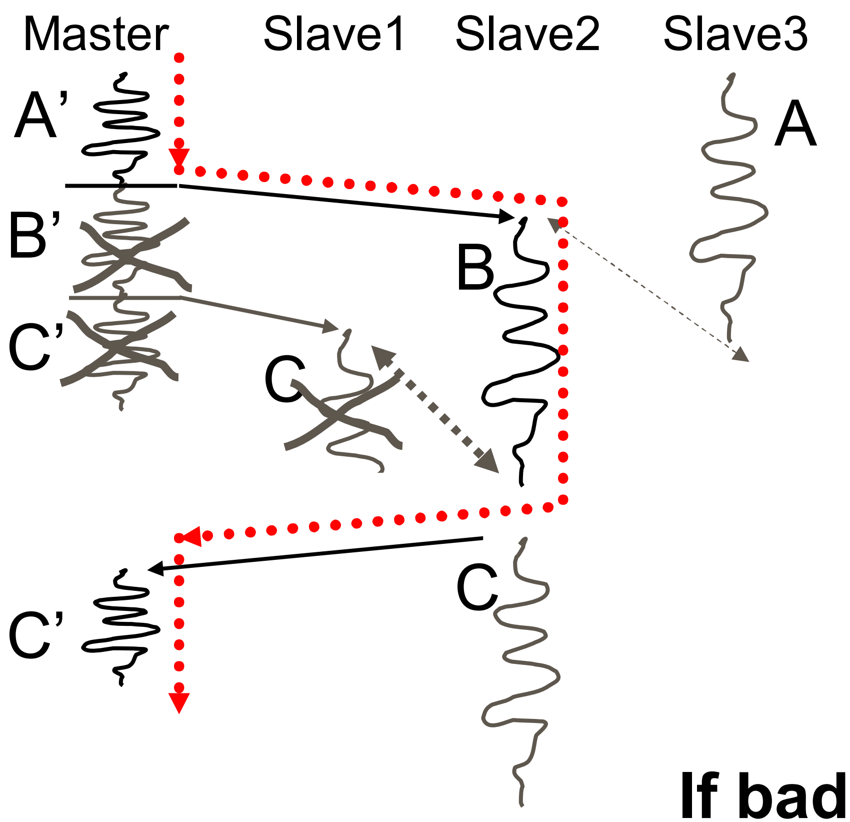
Verify B's inputs with A's outputs; commit state

Bad Checkpoint @ C

Detected at end of B

Squash, restart from architected state

MSSP Critical Path



If checkpoints correct:

- through distilled program
- no communication latency
- verification in background

Bad checkpoints:

- through original program
- interprocessor comm.

If bad checkpoints are rare:

- performance of distilled program
- tolerant of communication latency

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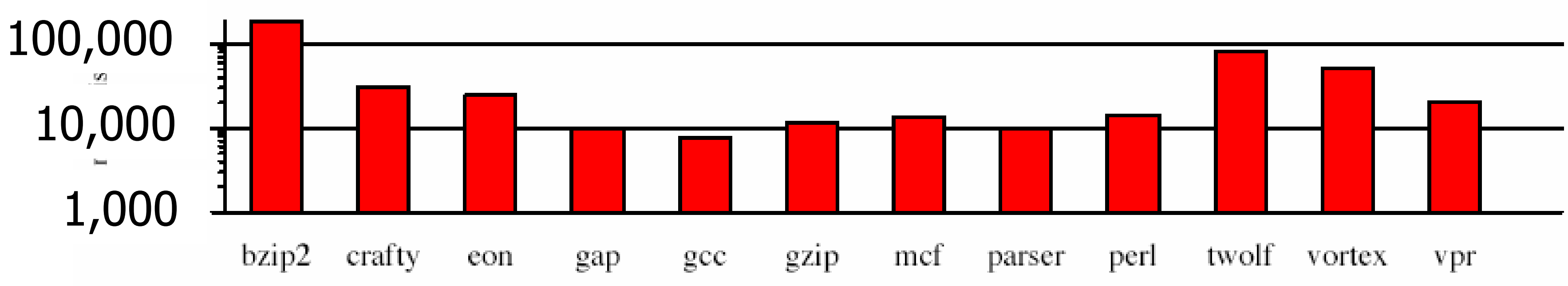
Methodology

- First-cut distiller
  - Static binary-to-binary translator
  - Simple control flow approximations
  - DCE, inlining, register re-allocation, save/restore elimination, code layout…
- HW model: 8-way CMP of 21264's
  - 10 cycle interconnect latency to shared L2
- Spec2000 Integer benchmarks on Alpha

Results Summary

- Distilled Programs can be accurate
  - 1 task misspeculation per 10,000 instructions
- Speedup depends on distillation
  - 1.25 h-mean: ranges from 1.0 to 1.7 (gcc, vortex)
  - (relative to uniprocessor execution)
- Modest storage requirements
  - Tens of kB at L2 for speculation buffering
- Decent latency tolerance
  - Latency 5 -> 20 cycles: 10% slowdown

Distilled Program Accuracy



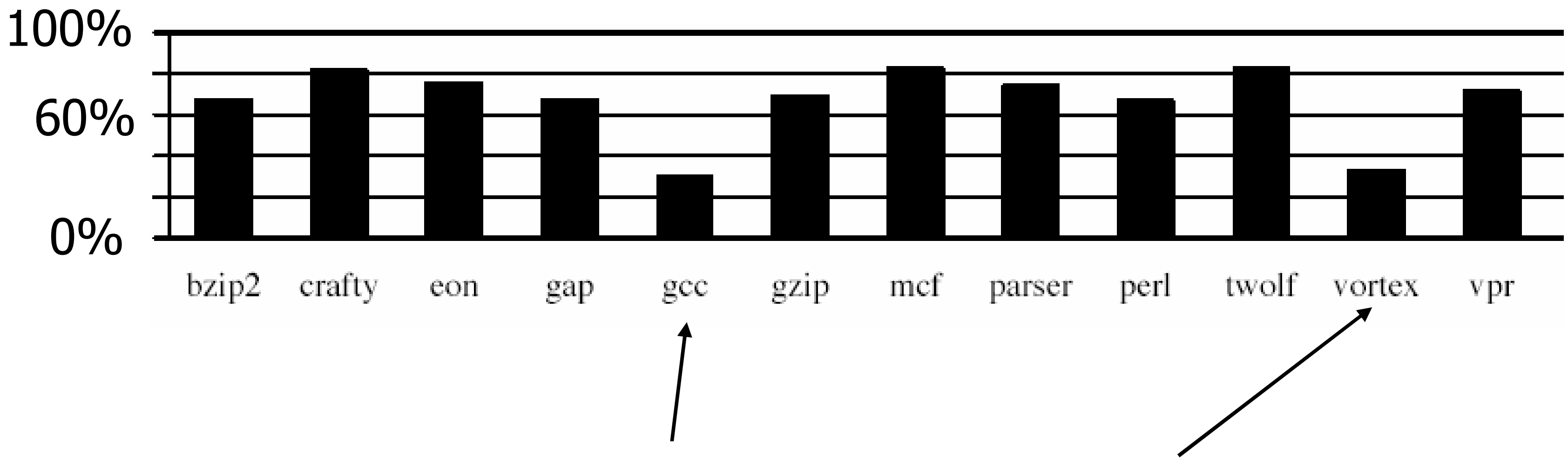
Average distance between task misspeculations:

> 10,000 original program instructions

Distillation Effectiveness

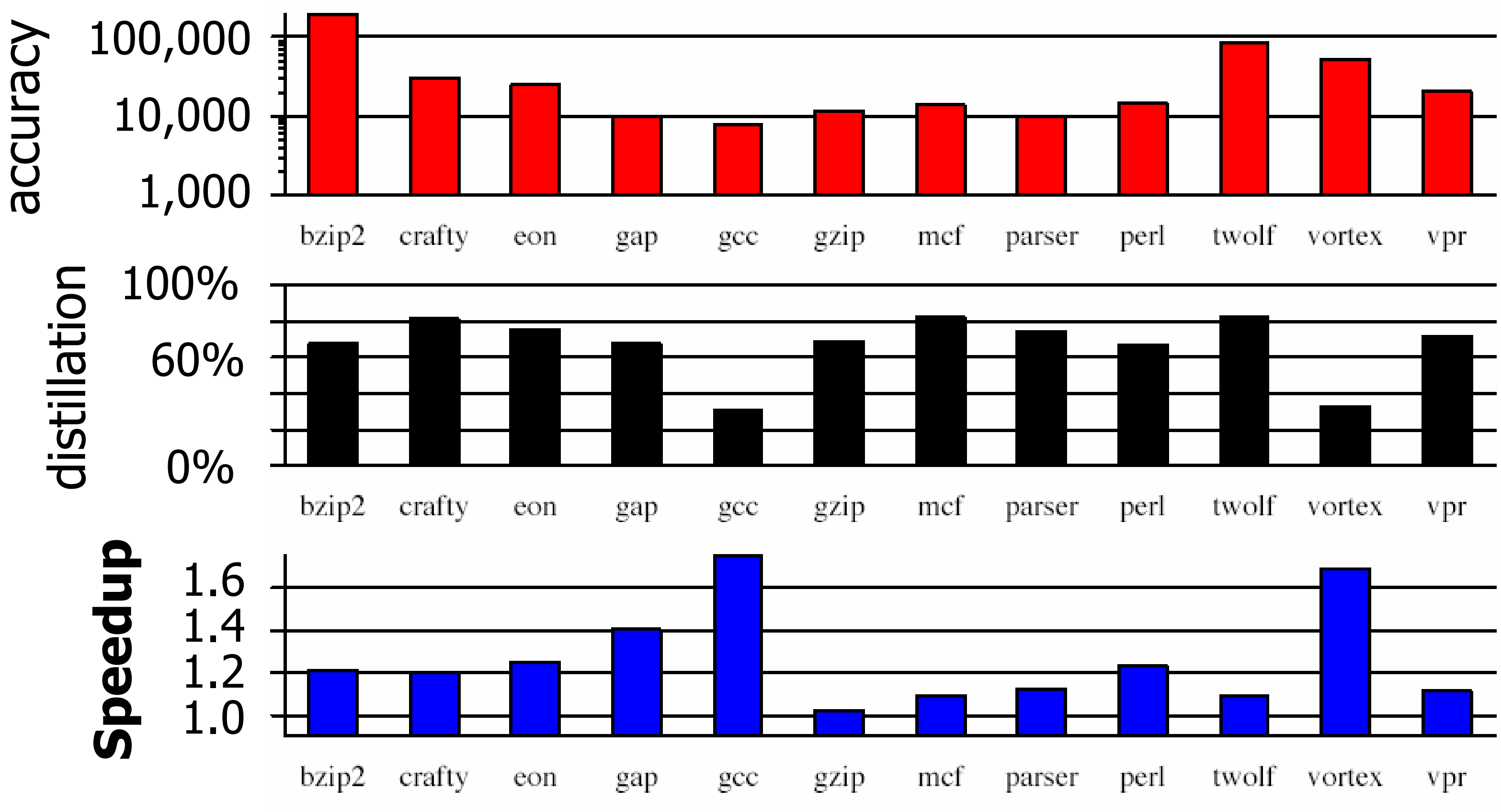
$$\frac{\text{Instructions retired by Master}}{\text{Instructions retired by Slave}}$$ (distilled program) / (original program

(not counting nops)



Up to two-thirds reduction

Performance



Performance scales with distillation effectiveness

Related Work

- Slipstream
- Speculative Multithreading
- Pre-execution
- Feedback-directed Optimization
- Dynamic Optimizers

Summary

- Don’t waste core on predictable things
  - “Distill” out predictability from programs
- Verify predictions with original program
  - Split into tasks: parallel validation
  - Achieve the throughput to keep up
- Has some nice attributes (ask offline)
  - Can support legacy binaries, latency tolerant, low verification cost, complements explicit parallelism