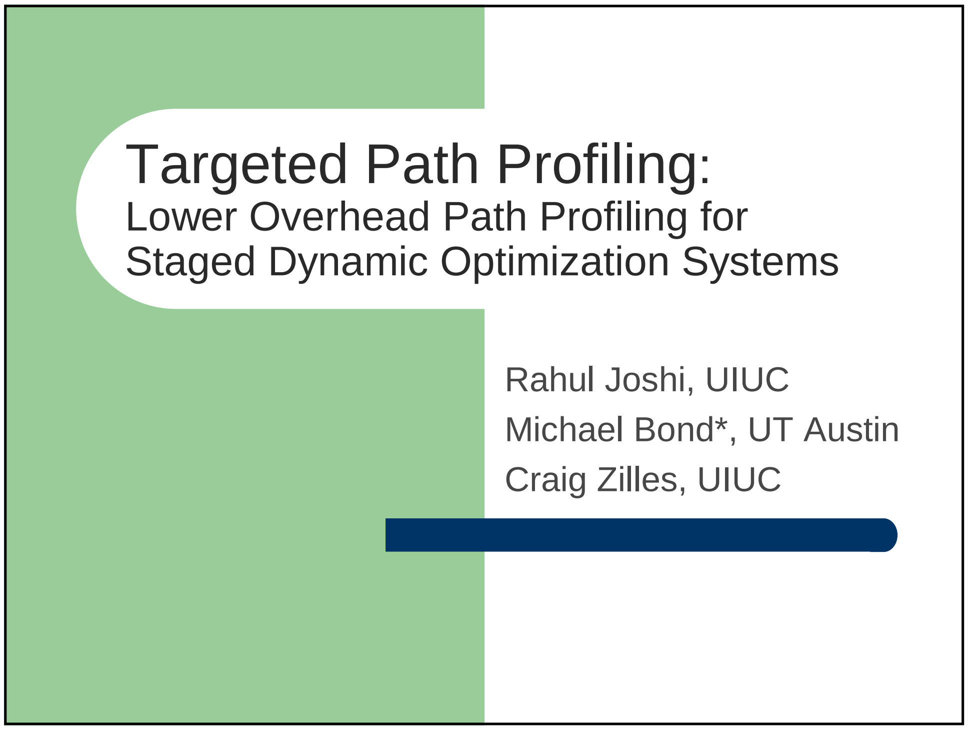
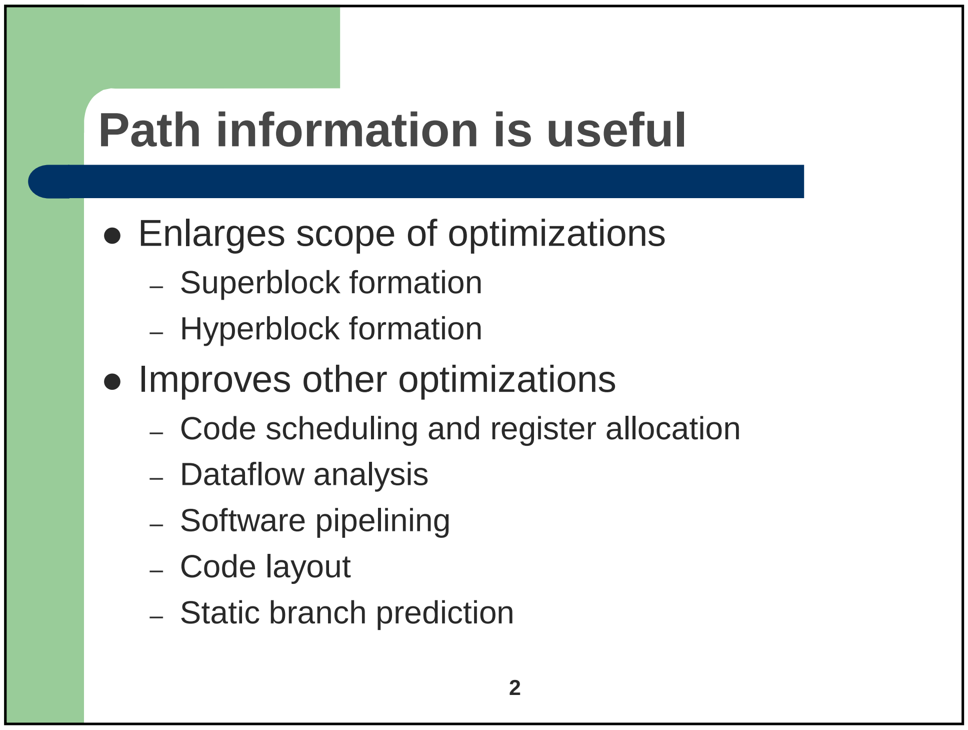


Targeted Path Profiling:
Lower Overhead Path Profiling for Staged Dynamic Optimization Systems

Rahul Joshi, UIUC
Michael Bond*, UT Austin
Craig Zilles, UIUC

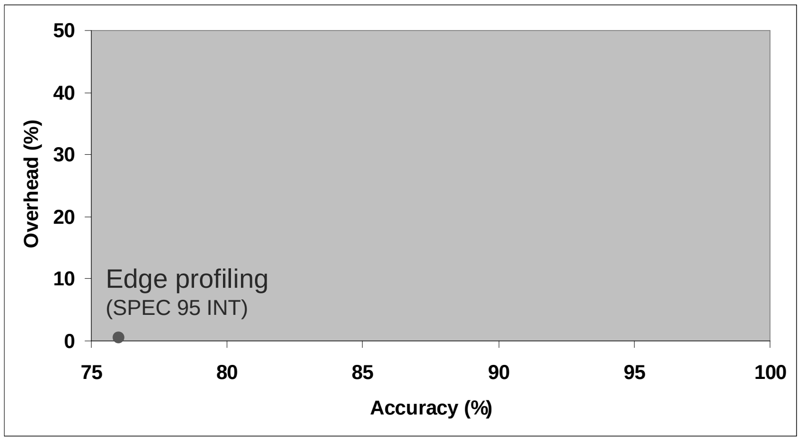


Path information is useful

- Enlarges scope of optimizations
  - Superblock formation
  - Hyperblock formation
- Improves other optimizations
  - Code scheduling and register allocation
  - Dataflow analysis
  - Software pipelining
  - Code layout
  - Static branch prediction

2

Overhead vs. accuracy



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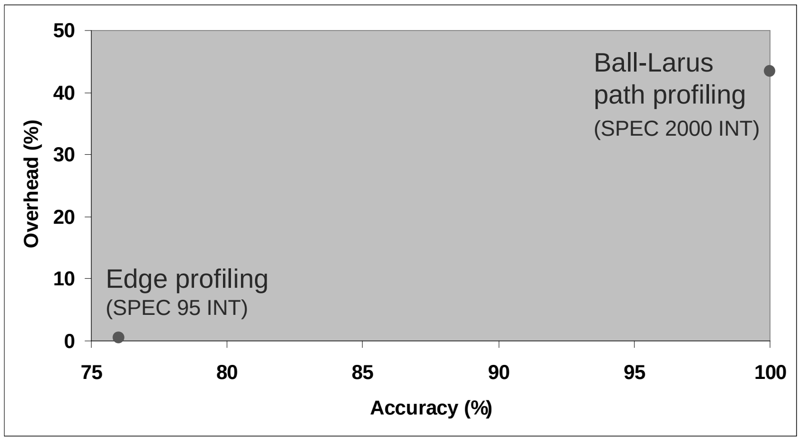
Overhead vs. accuracy



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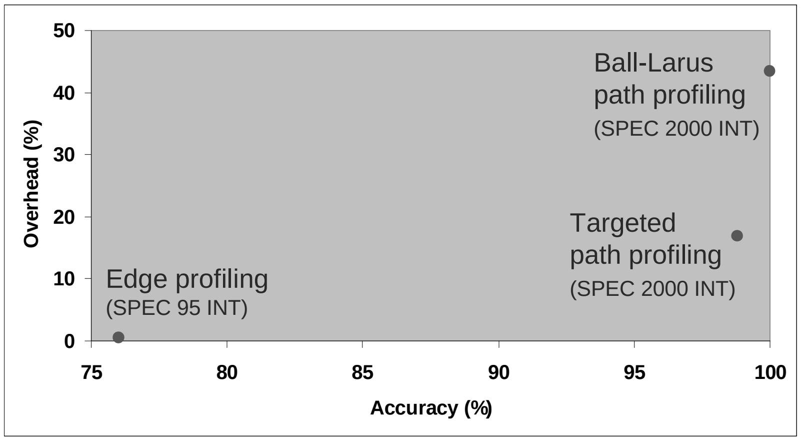
Overhead vs. accuracy



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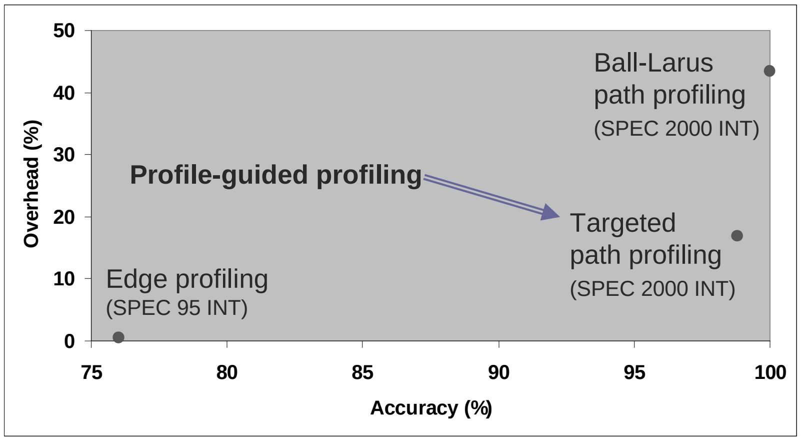
Overhead vs. accuracy



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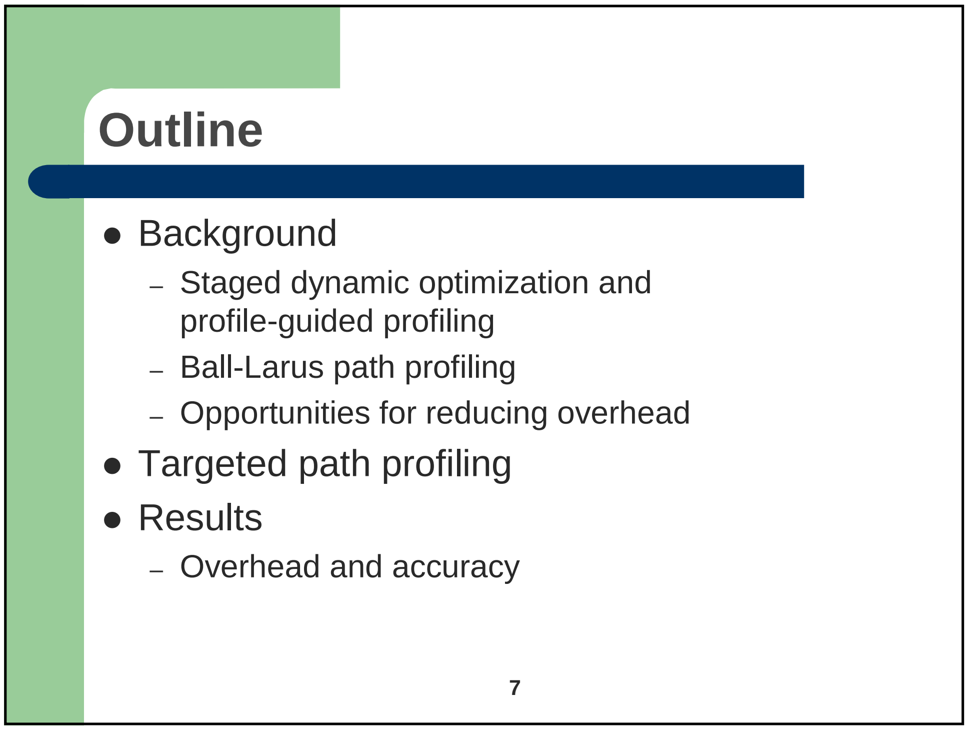
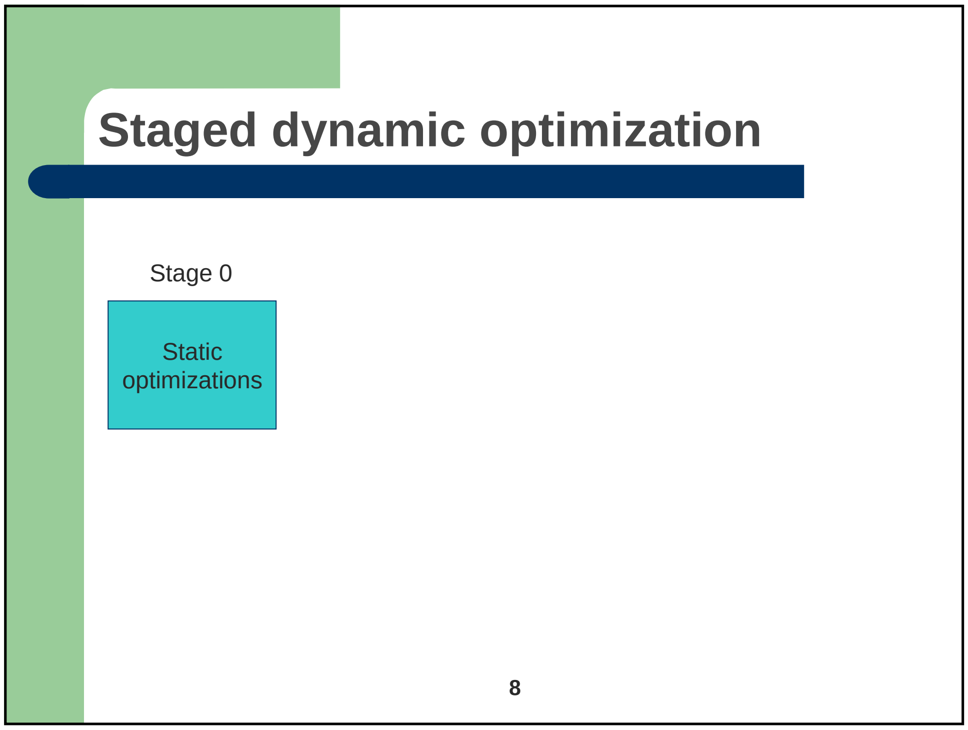


Outline

- Background
  - Staged dynamic optimization and profile-guided profiling
  - Ball-Larus path profiling
  - Opportunities for reducing overhead
- Targeted path profiling
- Results
  - Overhead and accuracy

7

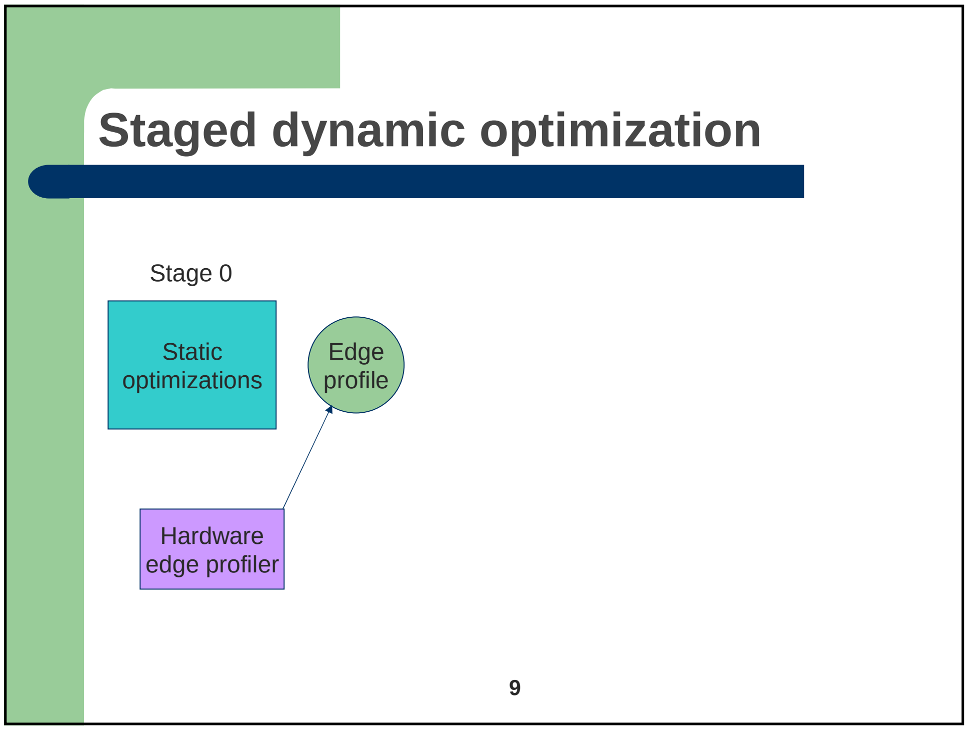


Staged dynamic optimization

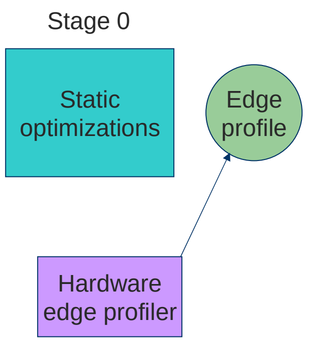
Stage 0

Static optimizations

8



Staged dynamic optimization



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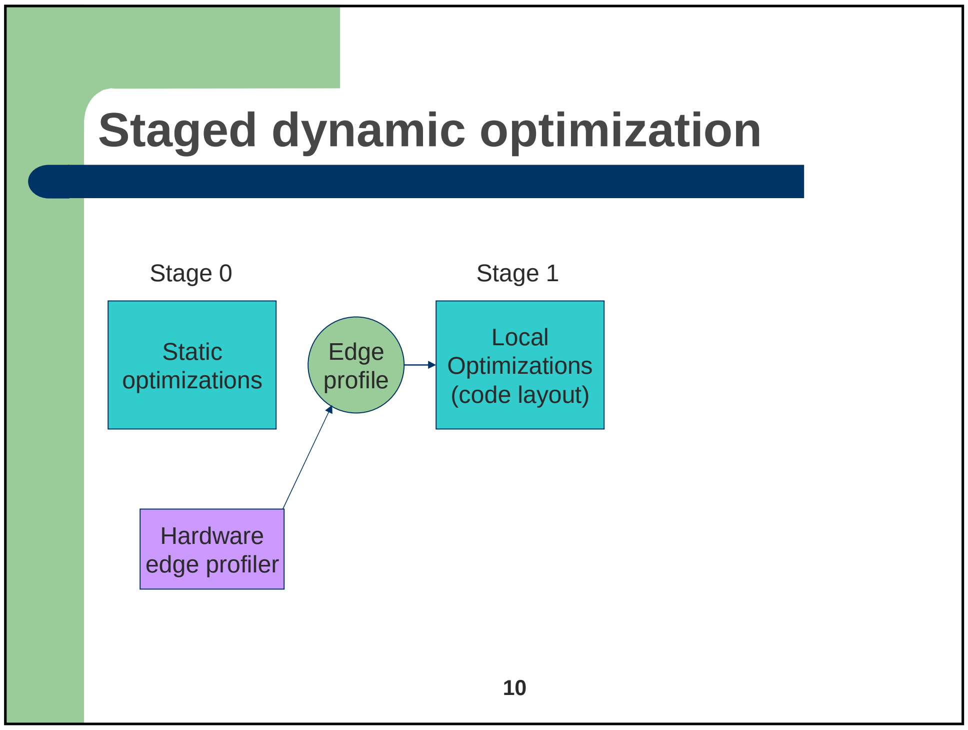
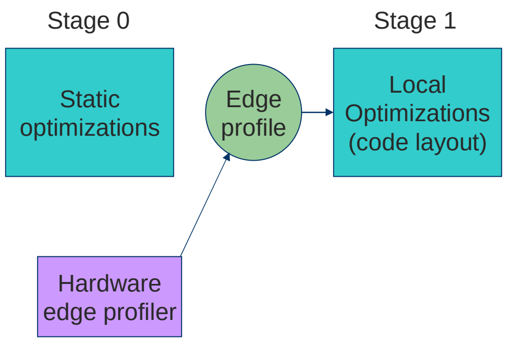
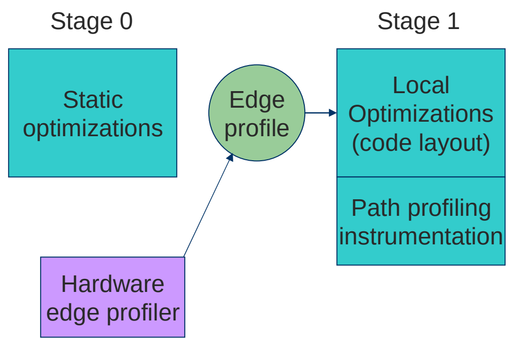


Staged dynamic optimization



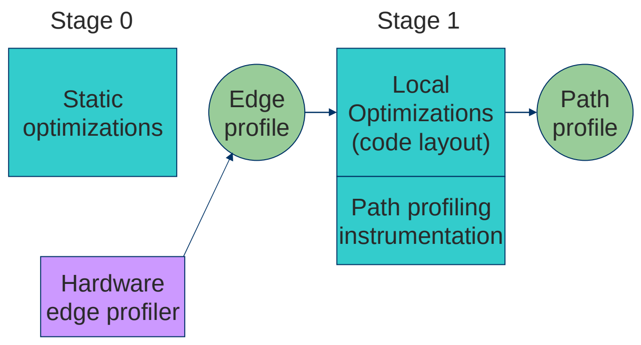
10

Staged dynamic optimization



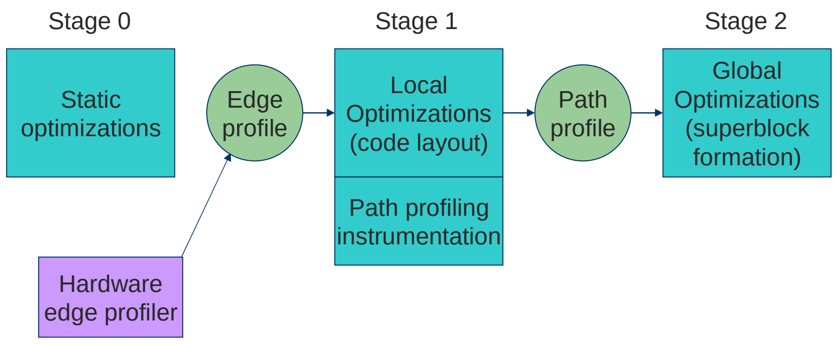
11

Staged dynamic optimization



12

Staged dynamic optimization


Stage 0
Stage 1
Stage 2
Static optimizations
Edge profile
Local Optimizations (code layout)
Path profile
Global Optimizations (superblock formation)
Path profiling instrumentation
Hardware edge profiler

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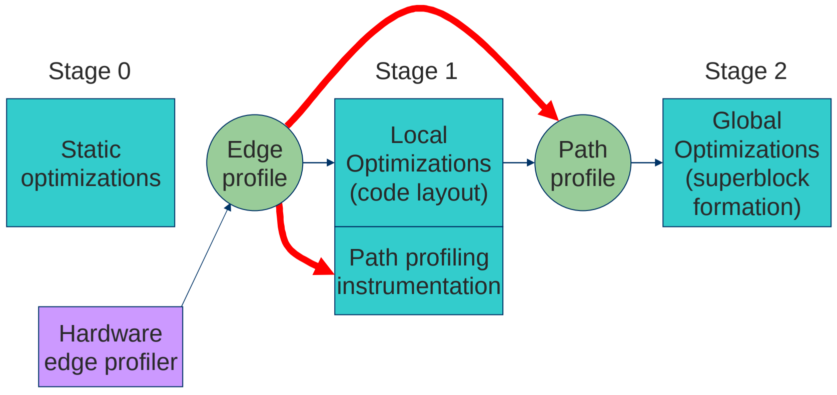
Profile-guided profiling


Stage 0
Stage 1
Stage 2
Static optimizations
Edge profile
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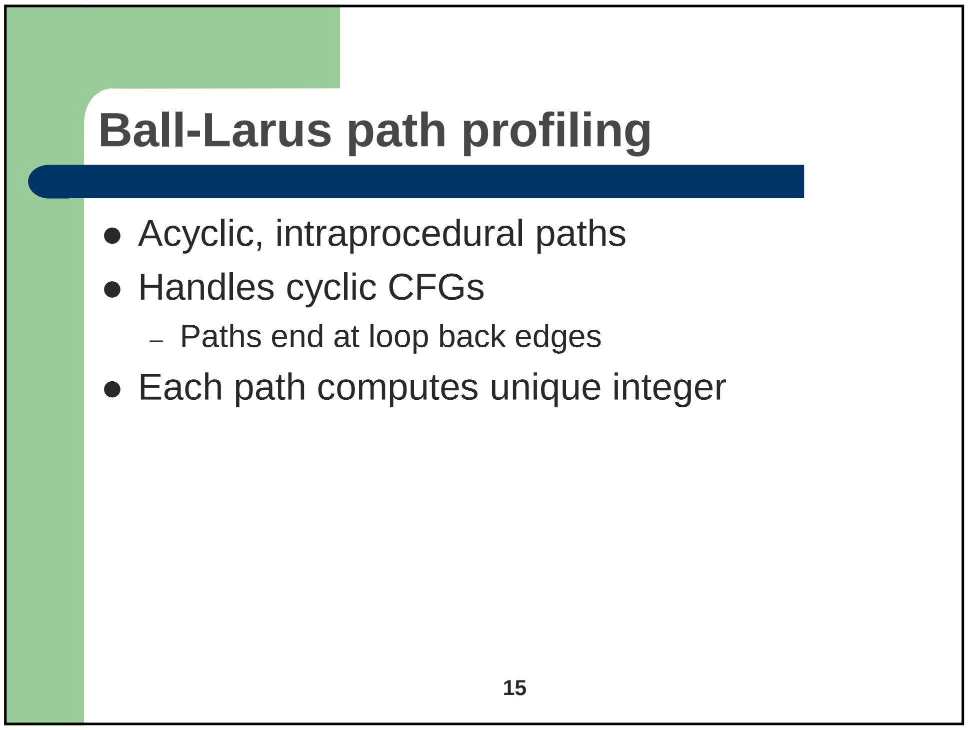
Path profile
Global Optimizations (superblock formation)
Path profiling instrumentation
Hardware edge profiler

14



Ball-Larus path profiling

- Acyclic, intraprocedural paths
- Handles cyclic CFGs
  - Paths end at loop back edges
- Each path computes unique integer

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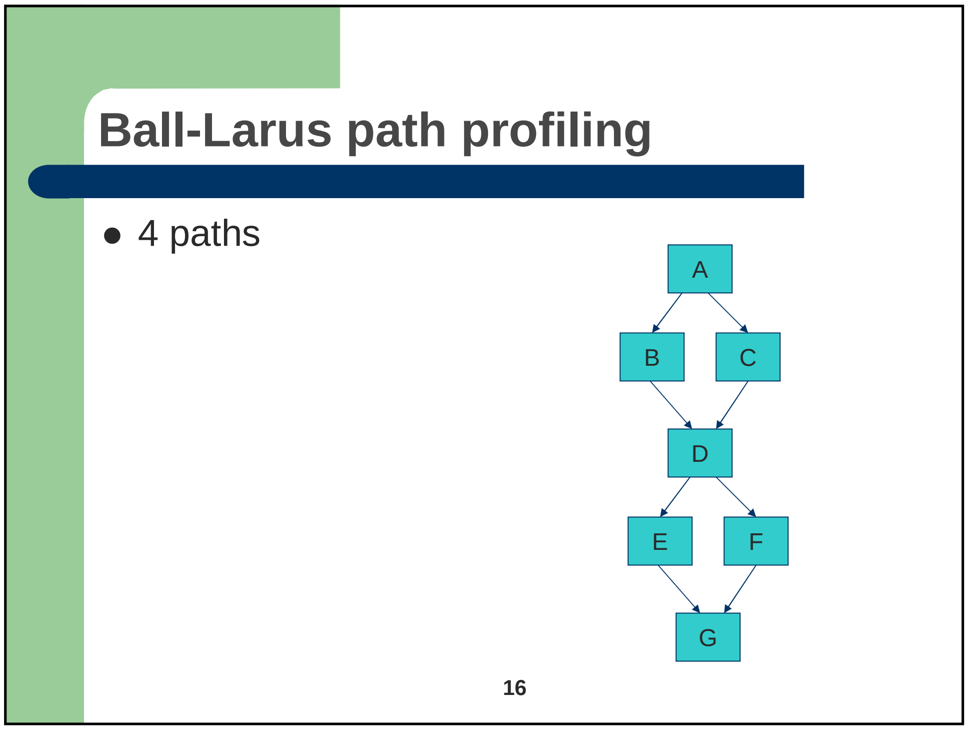
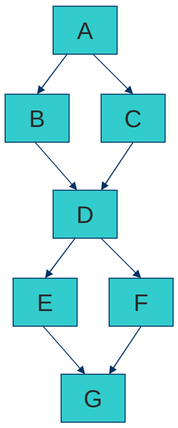


Ball-Larus path profiling

- 4 paths

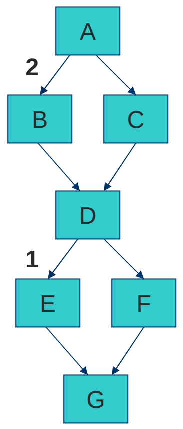


$$\begin{tikzcd} & A \arrow[dl] \arrow[dr] & \\ B \arrow[dr] & & C \arrow[dl] \\ & D \arrow[dl] \arrow[dr] & \\ E \arrow[dr] & & F \arrow[dl] \\ & G & \end{tikzcd}$$

16

Ball-Larus path profiling

- 4 paths
- Each path computes unique integer



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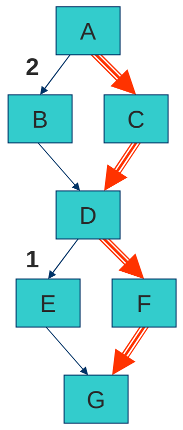
Ball-Larus path profiling

- 4 paths
- Each path computes unique integer

- Path 0



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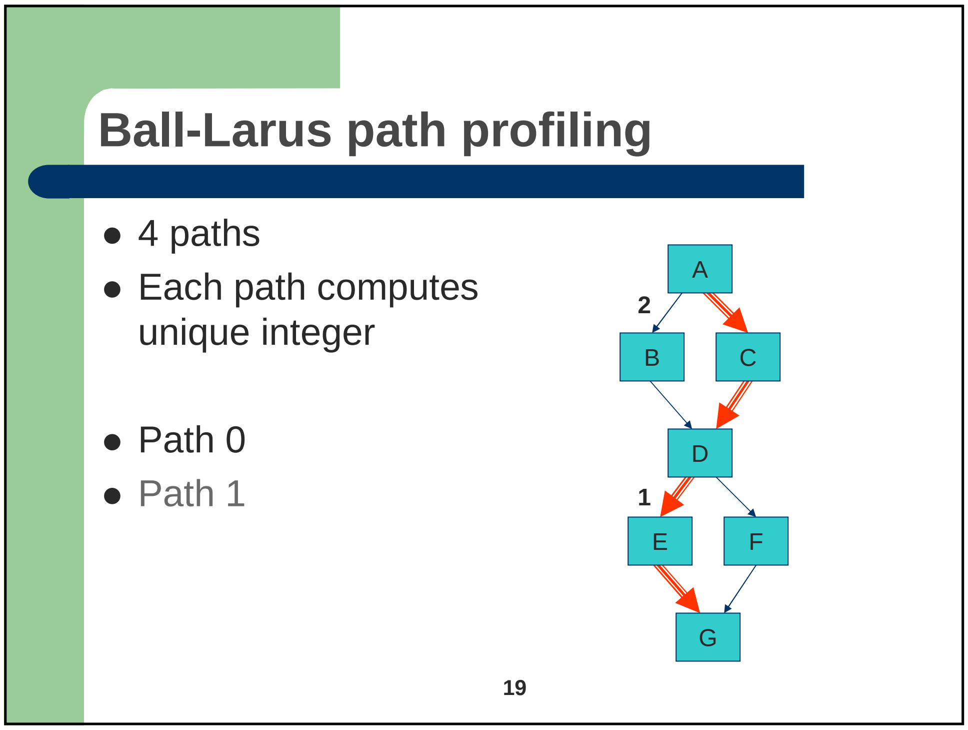
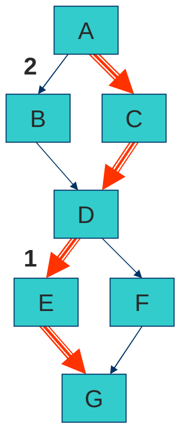


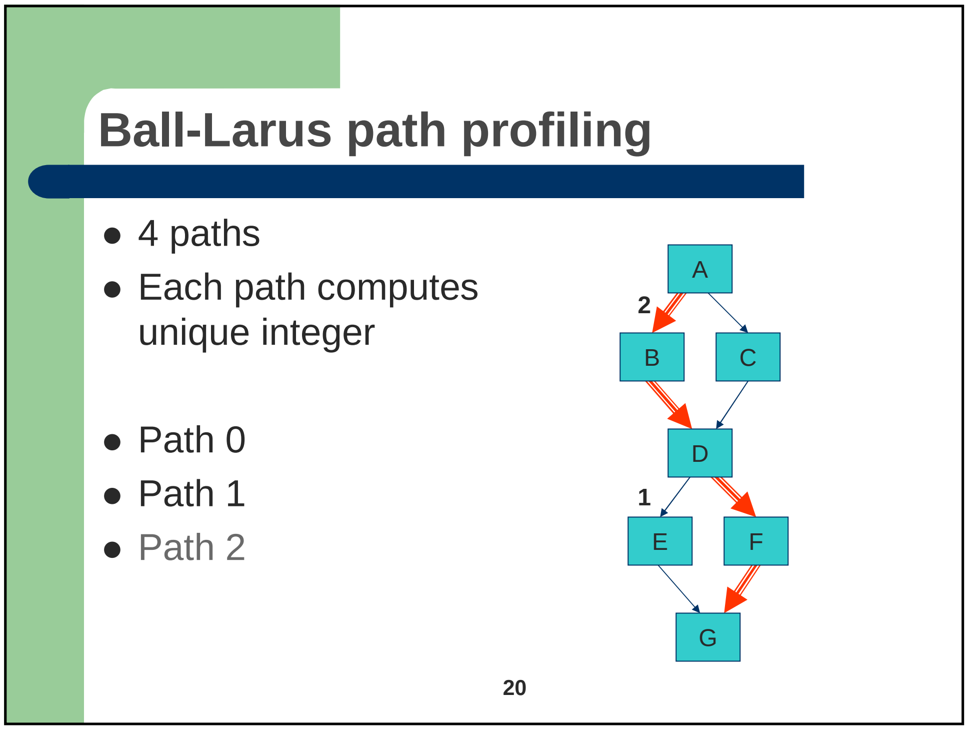
Ball-Larus path profiling

- 4 paths
- Each path computes unique integer

- Path 0
- Path 1



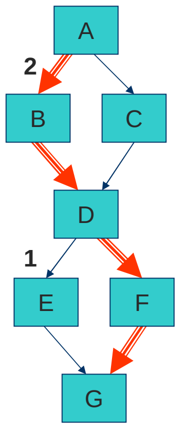
19



Ball-Larus path profiling

- 4 paths
- Each path computes unique integer

- Path 0
- Path 1
- Path 2



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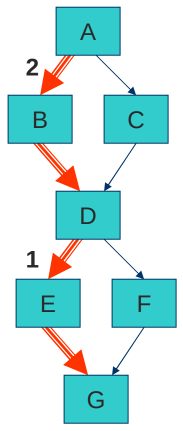
Ball-Larus path profiling

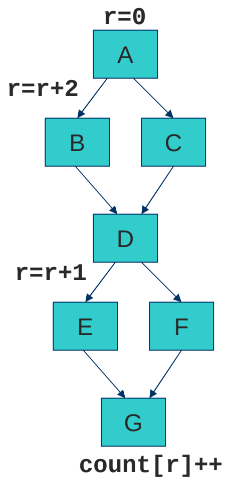
- 4 paths
- Each path computes unique integer

- Path 0
- Path 1
- Path 2
- Path 3



Ball-Larus path profiling

- `r`: path register
- `count`: array of path frequencies



Overhead in Ball-Larus path profiling

	SPEC 95	SPEC 2000
gcc	96%	87%
INT Avg	41%	43%
FP Avg	12%	22%
Overall Avg	**28%**	**37%**

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Overhead in Ball-Larus path profiling

	SPEC 95	SPEC 2000
gcc	96%	87%
INT Avg	41%	43%
FP Avg	12%	22%
Overall Avg	**28%**	**37%**

- Opportunities for reducing overhead?
  - When there are many paths
  - When edge profile gives perfect path profile

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Routines with many paths

- Many *possible* paths
  - Exponential in number of edges
  - Can't use array of counters
- Number of *taken paths* small
  - Ball-Larus uses hash table
  - Hash function call expensive
    - Hashed path ~5 times overhead

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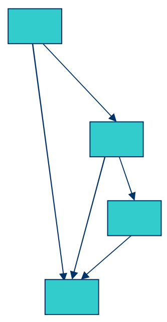
Edge profile gives perfect path profile



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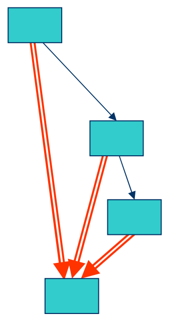
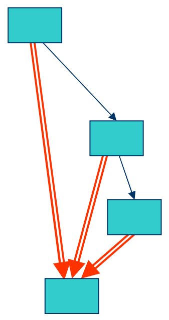
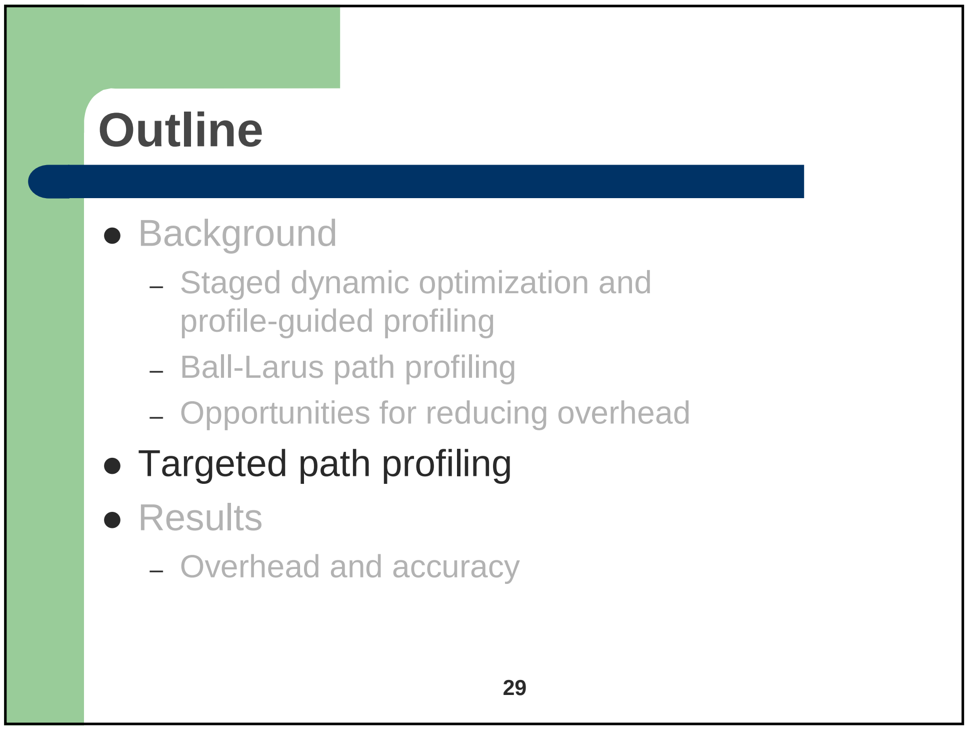
Edge profile gives perfect path profile



Edge profile gives perfect path profile

- An *obvious path* contains an edge that is only on that path
  - Path uniquely identified by edge
  - Path freq = edge freq
- If all paths obvious, edge profile gives perfect path profile





Outline

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  - Opportunities for reducing overhead
- Targeted path profiling
- Results
  - Overhead and accuracy

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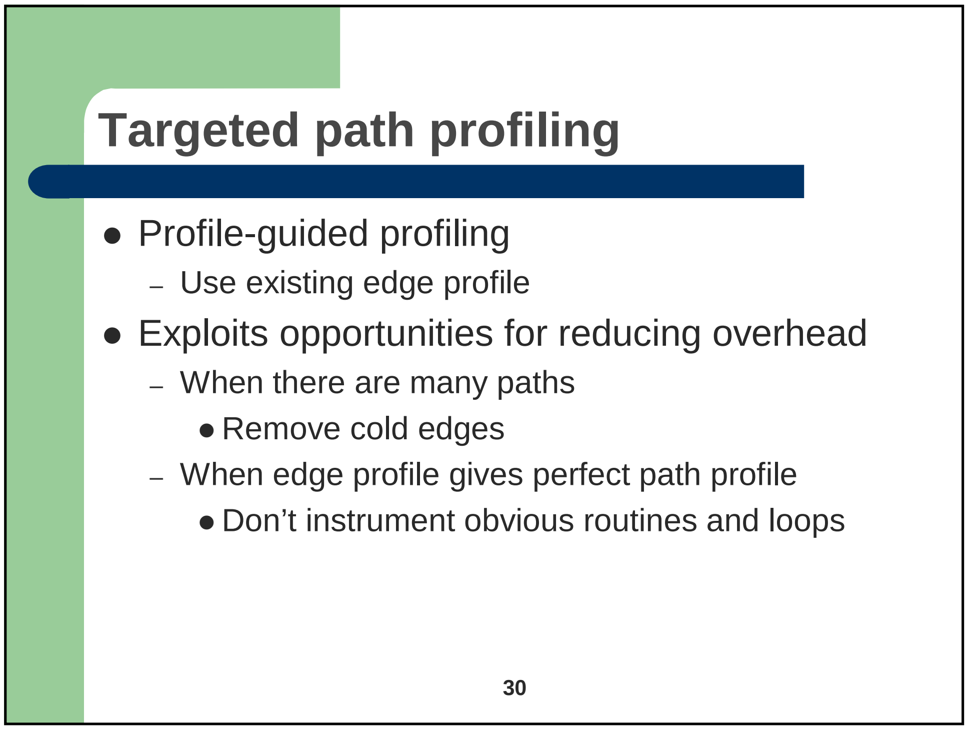

Targeted path profiling

- Profile-guided profiling
  - Use existing edge profile
- Exploits opportunities for reducing overhead
  - When there are many paths
    - Remove cold edges
  - When edge profile gives perfect path profile
    - Don't instrument obvious routines and loops

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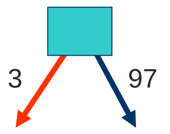
Removing cold edges

- Examine relative execution frequency of each branch

```
if (relFreq < threshold)
  edge is cold
```



Removing cold edges

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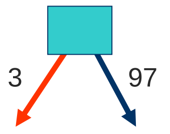

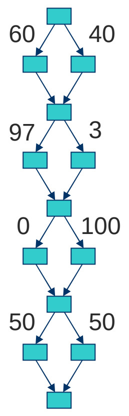

Removing cold edges

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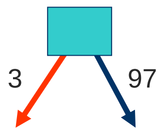

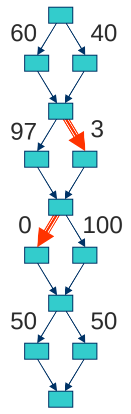

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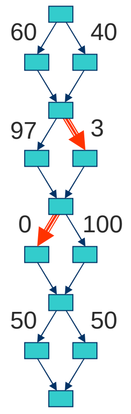
Removing cold edges

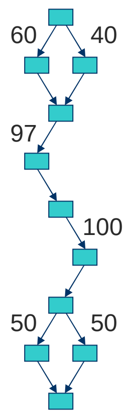
- A path that contains a cold edge is a *cold path*
- Removing an edge may halve number of paths



34

Removing cold edges

- A path that contains a cold edge is a *cold path*
- Removing an edge may halve number of paths
- Number of paths: 16 → 4



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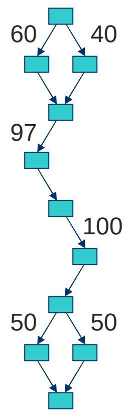
Removing cold edges

- A path that contains a cold edge is a *cold path*
- Removing an edge may halve number of paths
- Number of paths: 16 → 4

Goal: hashed → non-hashed



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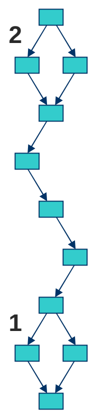
Removing cold edges

- Remaining paths potentially hot
- 4 paths → [0, 3]



Removing cold edges

- Remaining paths potentially hot
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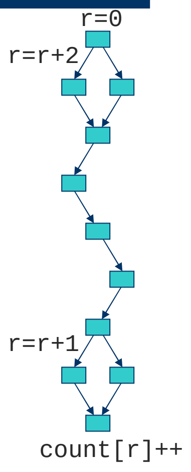
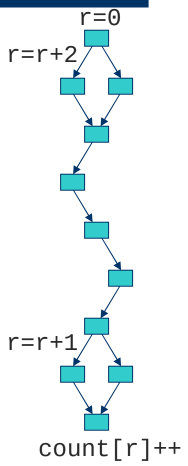


Removing cold edges

- What if cold edge taken?



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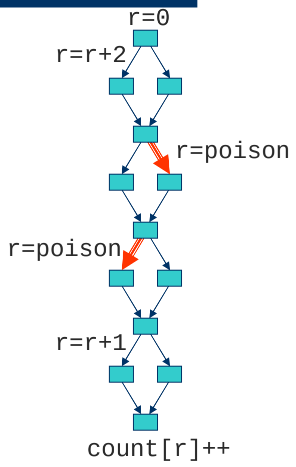
Removing cold edges

- What if cold edge taken?

- Cold edges poison path



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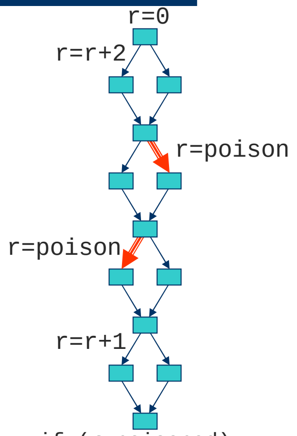
Removing cold edges

- What if cold edge taken?
- Cold edges poison path
- Instrumentation checks for poisoned path



```
if (r poisoned)
  cold_counter++
else
  count[r]++
```

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Checking for poison

```
if (r poisoned)
  cold_counter++
else
  count[r]++
```

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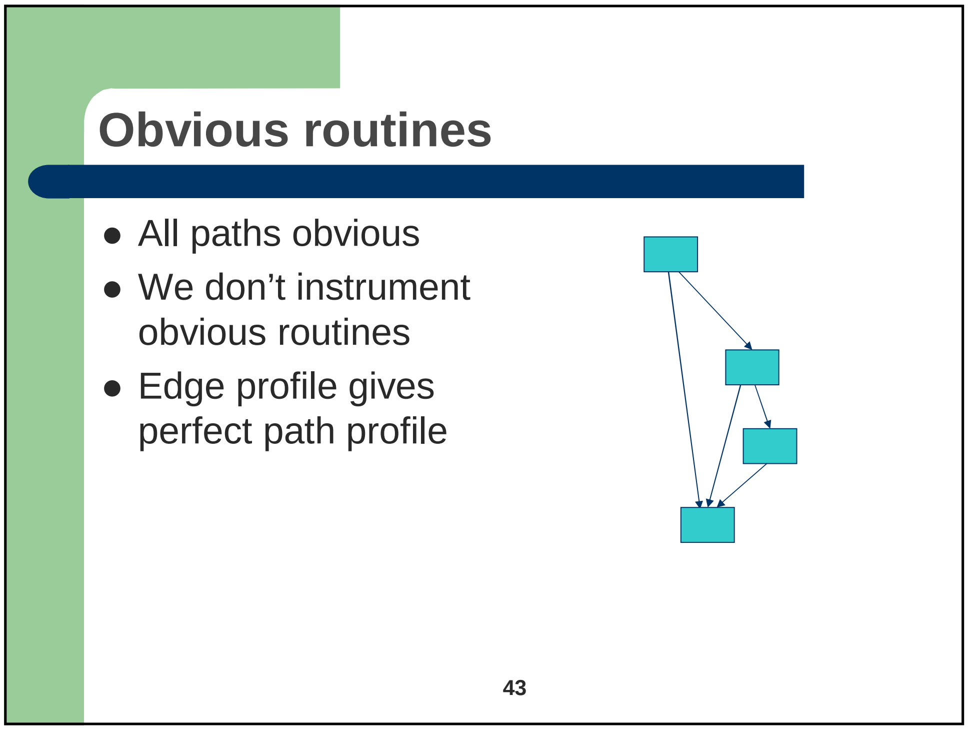
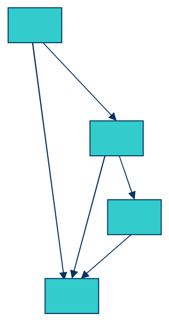


Obvious routines

- All paths obvious
- We don’t instrument obvious routines
- Edge profile gives perfect path profile



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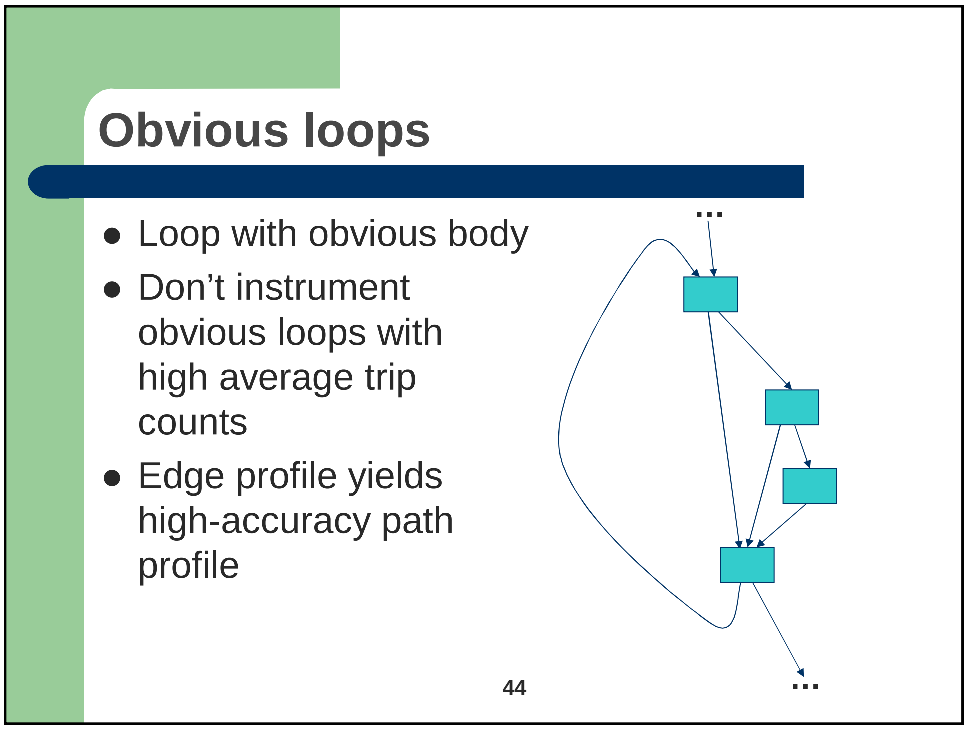
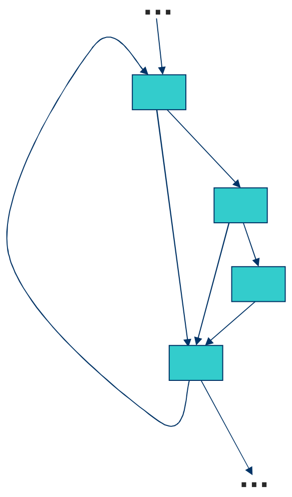


Obvious loops

- Loop with obvious body
- Don’t instrument obvious loops with high average trip counts
- Edge profile yields high-accuracy path profile



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Obvious loops

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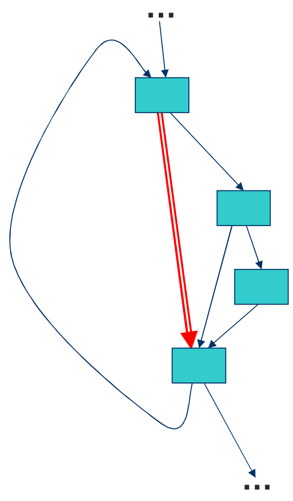
- Edge profile yields high-accuracy path profile



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Summary of our techniques

- Remove cold edges
  - Eliminates many cold paths
  - Count paths with array (instead of hash table)
- Don’t instrument obvious routines and loops
  - Edge profile derives path profile

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Outline

- Background
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Implementation

- Static profiling
- **PP**: tool for path profiling
- **TPP**: tool for targeted path profiling
- Tools instrument native SPARC executables
  - SPEC 95 **`ref`**
  - SPEC 2000 **`ref`**

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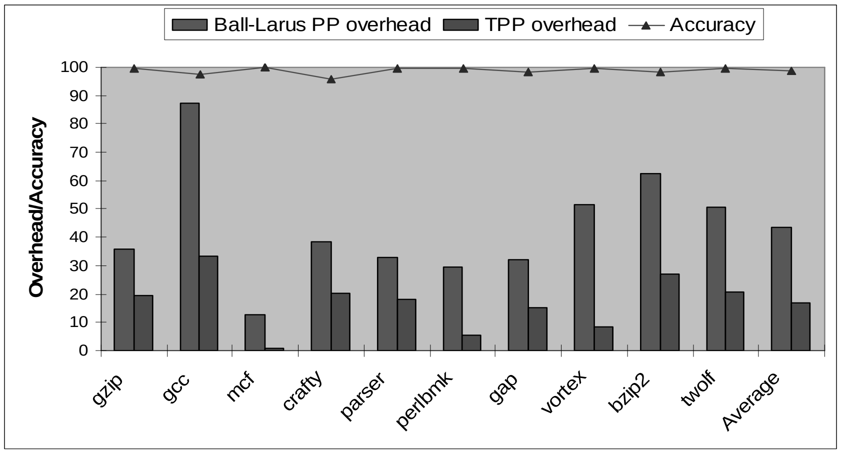
Results: SPEC 2000 INT



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Where does benefit come from?

- Cold path elimination alone: 60%
- Add obvious path elimination: + 40%

- Little benefit from obvious path elimination alone

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Related work

- Dynamo [Bala et al. ‘00]
  - Successful online path-guided optimization
  - “Bails out” when no dominant path
- Instrumentation sampling [Arnold & Ryder ‘01]
  - Orthogonal to targeted path profiling
- Selective path profiling [Apiwattanapong & Harrold ’02]
  - Useful when only a few paths of interest

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Summary

- Profile-guided profiling in a staged dynamic optimization system
- Two synergistic techniques
  - Remove cold paths
  - Don’t instrument obvious routines and loops
- Reduces overhead by half (SPEC 95) to two-thirds (SPEC 2000)
- High accuracy: ~99%

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