Phase-based Tuning

for Better Utilization of Performance-Asymmetric Multicore Processors

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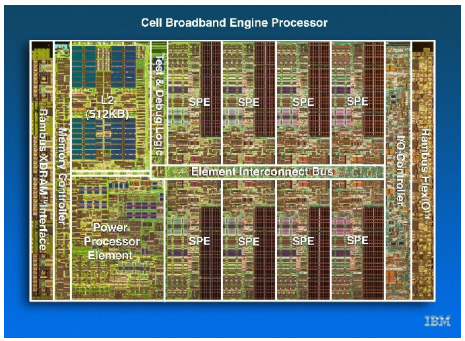
Performance Asymmetric Multicores

- **What**: Cores may have different characteristics

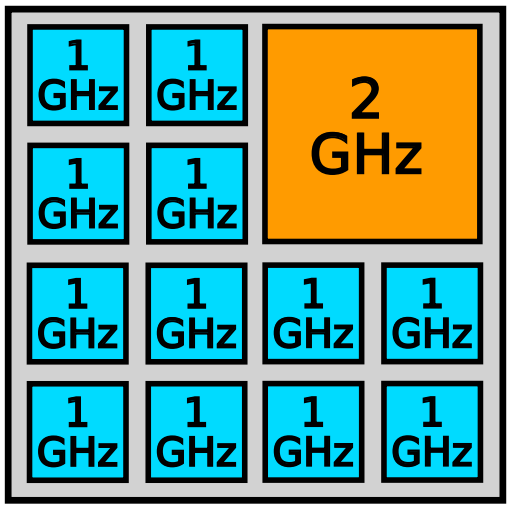
  clock speed, cache size, branch predictors, in/out-of order, etc.
- **Why** more efficient than homogeneous[1]:
  - space
  - heat
  - power
  - performance-power ratio
  - parallelism
- Asymmetry in symmetric systems.



IBM's Cell

AMD's Fusion

Intel's Sandybridge

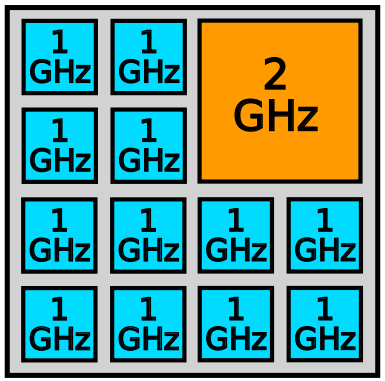


Asymmetric Multicore

[1] R. Kumar et al. ISCA '04

Overview

Problem: Efficient utilization of asymmetric cores.
Challenge: Match resource needs of threads to cores.



Asymmetric Multicore

```
void foo(){
  for(i=0:n)
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Workload

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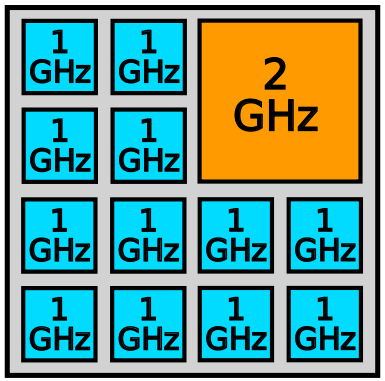

Asymmetric Multicore

```
void foo(){
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```

??

```
void foo(){
  sw(fast)
  for(i=0:n)
  //cpu intense
  sw(slow)
  for(i=0:n)
  //mem intense}
```

Workload

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Technical Challenge: Matching resource requirements

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  - Behavior of cores

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Insight: Use repeating behavior to reduce runtime overhead.

Contribution: Phase-based tuning

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Contribution: Phase-based tuning

Outline

- Problem in detail
- Overview of solution
- Evaluation

Problem

Technical Challenge: Matching resource requirements

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  - Behavior of cores
- Can we do this statically?
- Can we do this dynamically?

Static Solution?

Can we perform an efficient mapping statically?

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- Manually tuning requires expertise and is error prone.
  - What is the behavior of library calls?
  - How will my code perform on each core?

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  - How to create a portable implementation

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  - What is the behavior of library calls?
  - How will my code perform on each core?
- Resource need of threads may vary at runtime.
  - Program input may change performance
- Target architecture unknown statically (multiple targets).
  - How to create a portable implementation
- Resource availability may change due to contention
  - Other process on a core may demand more cache

Dynamic Solution?

- **Can we perform an efficient mapping dynamically?**

Dynamic Solution?

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- **Can we perform an efficient mapping dynamically?**
- Know program behavior, cores' resources, etc.
- Dynamically instrumentation/monitoring is expensive
  - ex: applying Pin to an application has $\geq$ 50% overhead[2]
  - Instrumentation code can introduce high overheads.

[2] Cohn, Pin Tutorial, 2009

Dynamic Solution?

- **Can we perform an efficient mapping dynamically?**
- Know program behavior, cores' resources, etc.
- Dynamically instrumentation/monitoring is expensive
  - ex: applying Pin to an application has $\geq$ 50% overhead[2]
  - Instrumentation code can introduce high overheads.
- **Idea:** Move work from dynamic to static analysis (hybrid)

[2] Cohn, Pin Tutorial, 2009

Hybrid Analysis Overview

Problem: Match code to cores based on resources needed/provided

Hybrid Analysis Overview

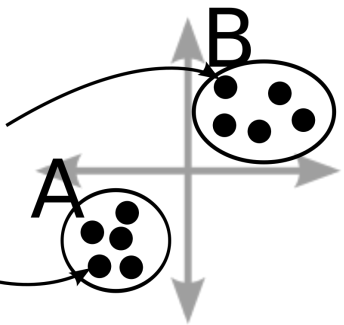
Start with program

```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```

Hybrid Analysis Overview

Cluster code into groups of similar behavior

```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```

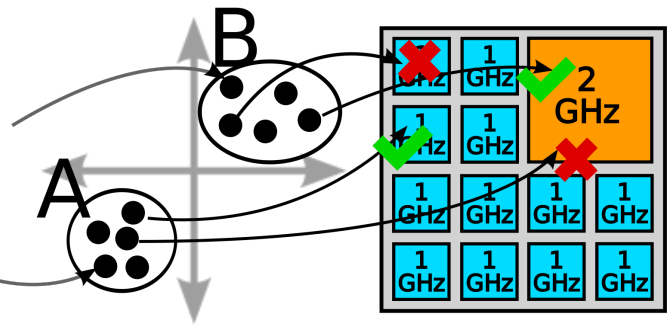


Advantage: No need to predict actual behavior, just similarity

Hybrid Analysis Overview

Run some program segments on each core type

```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```

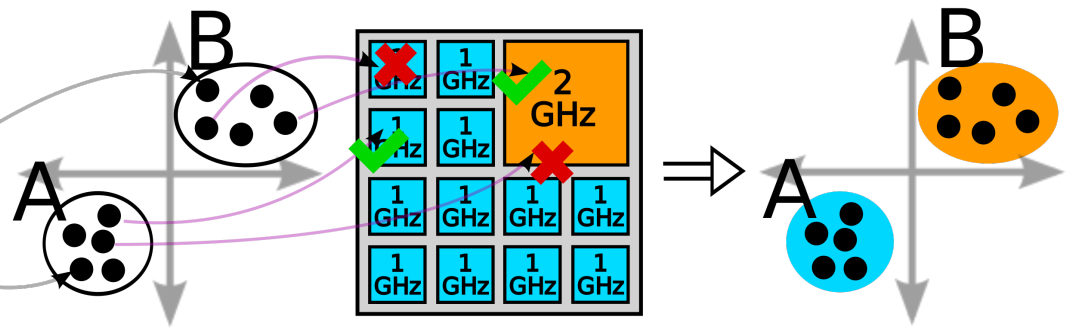


Advantage: Dynamically, no need to monitor all the code.

Hybrid Analysis Overview

Determine preferred mapping of each cluster

```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```

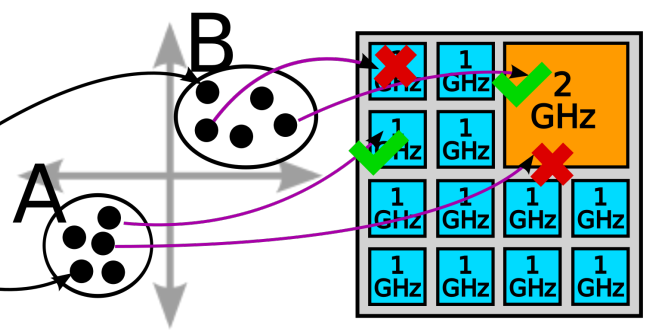


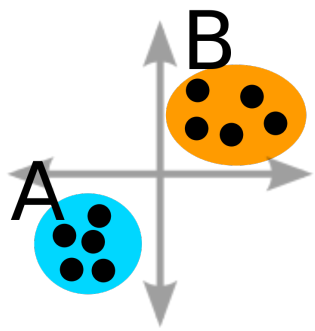
Advantage: Dynamically, no need to monitor all the code.

Hybrid Analysis Overview

Code now knows preferred core type

```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```



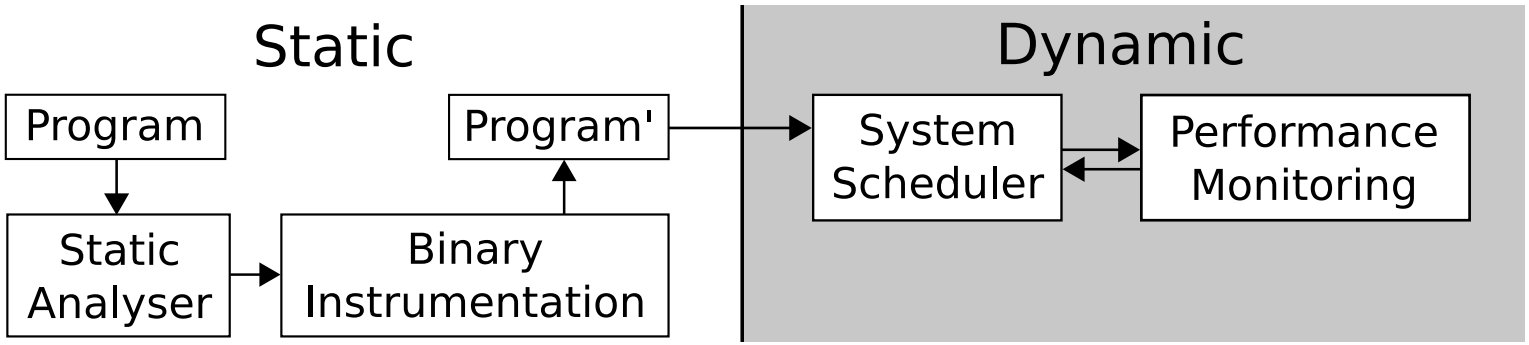



```
void foo(){
  opt(B)
  for(i=0:n)
  //cpu intense
  opt(A)
  for(i=0:n)
  //mem intense}
```

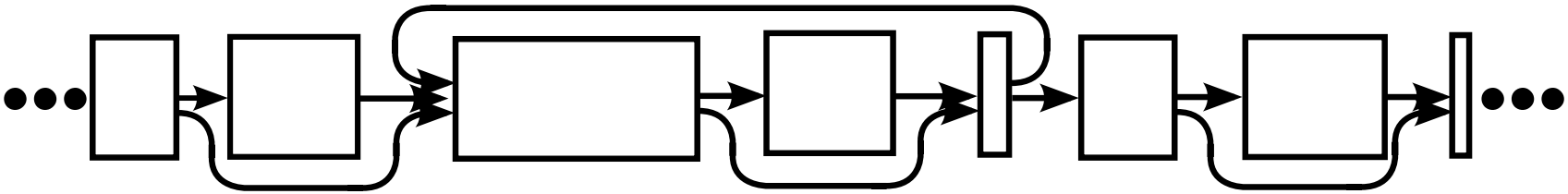
Approach Overview

Idea: Apply the same thread-to-core mapping to all approximately similar sections of code

- Statically
  - break the program into sections of code
  - determine approximate similarity between these sections
  - instrument where behavior changes
- Dynamically
  - monitor a few sections
  - make mapping decisions for similar sections



Static: Program



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}
```
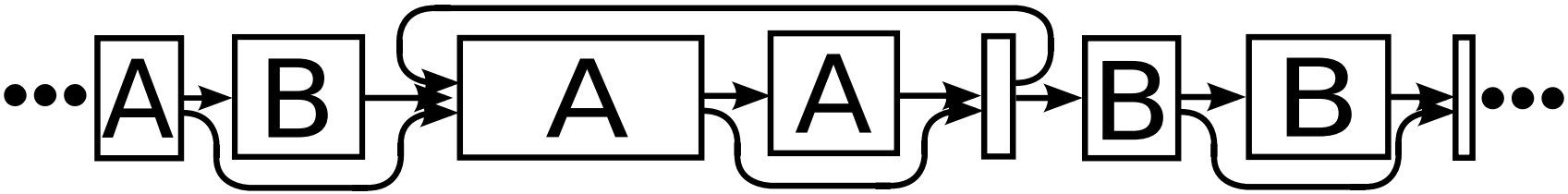

Static: Determine approximate similarity

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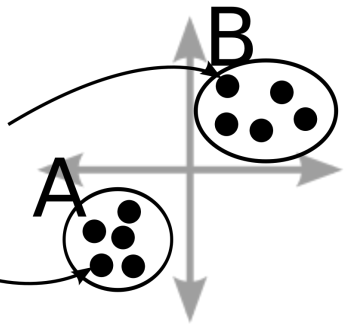
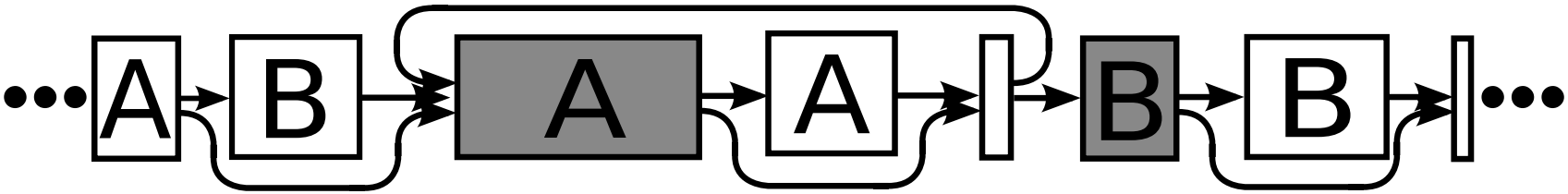


Static: Reduce number of transition points

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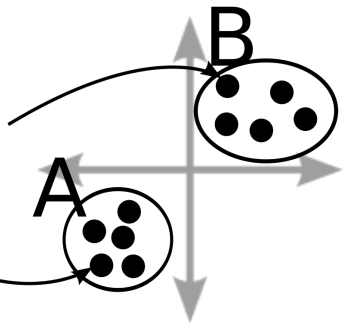
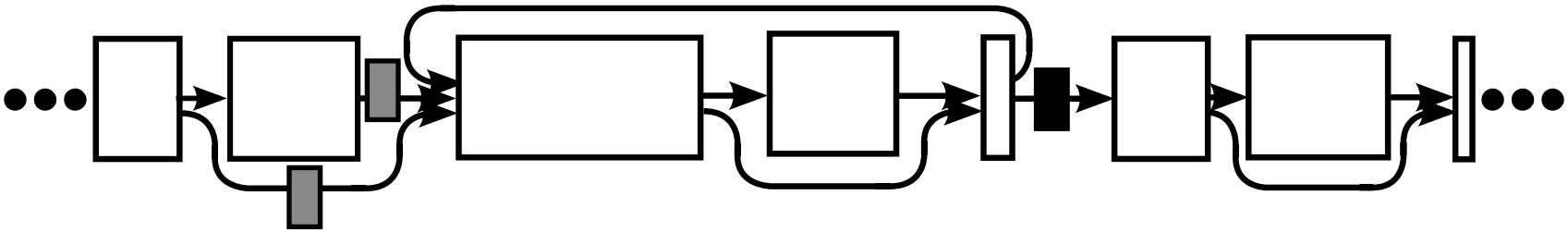


Static: Insert phase marks



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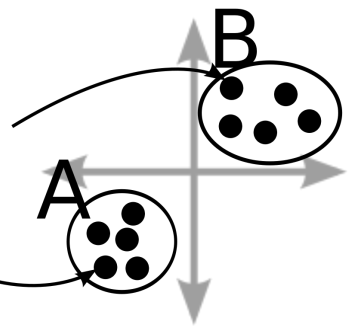


```
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  opt(B)
  for(i=0:n)
  //cpu intense
  opt(A)
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```
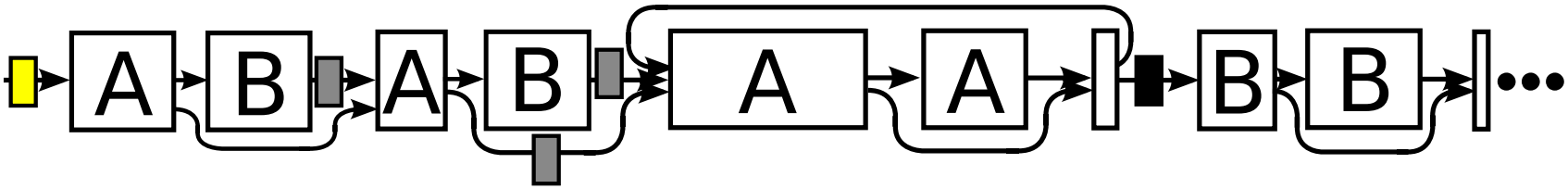

Static/Dynamic: Phase Marks

- Inserted on path where behavior is likely to change
  - Must pick “good” points to avoid overhead
  - For example, loop entry points
- Contains type information
- Contains dynamic analysis code
  - Monitor behavior if mapping is unknown
  - Switch cores if mapping is known

Dynamic: Monitor

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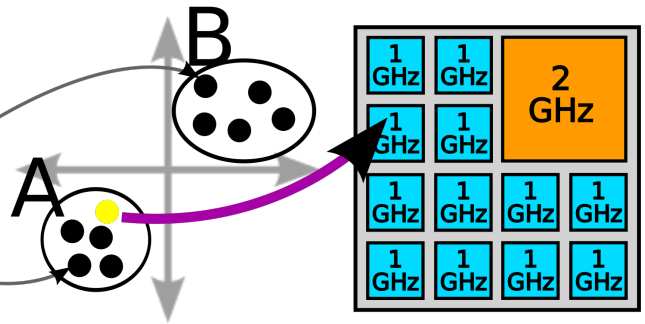
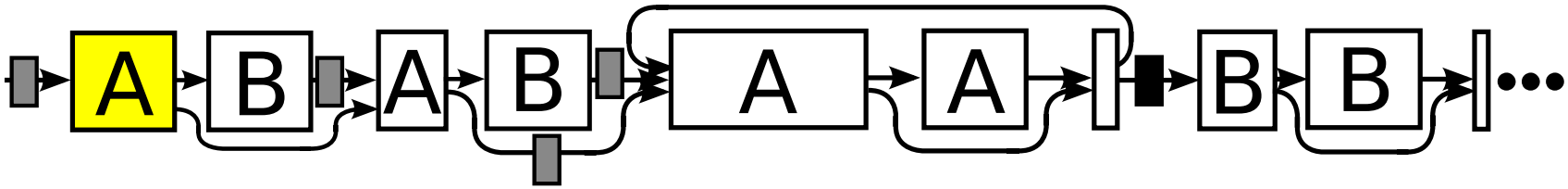


Dynamic: Run

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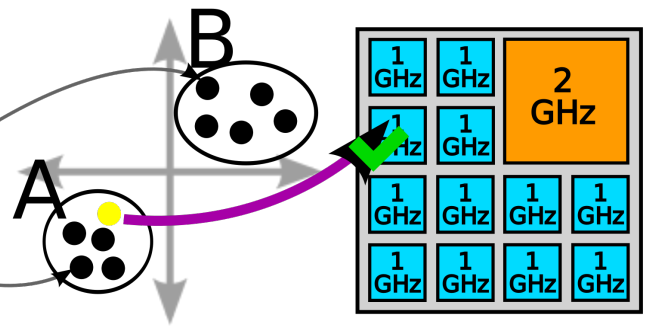

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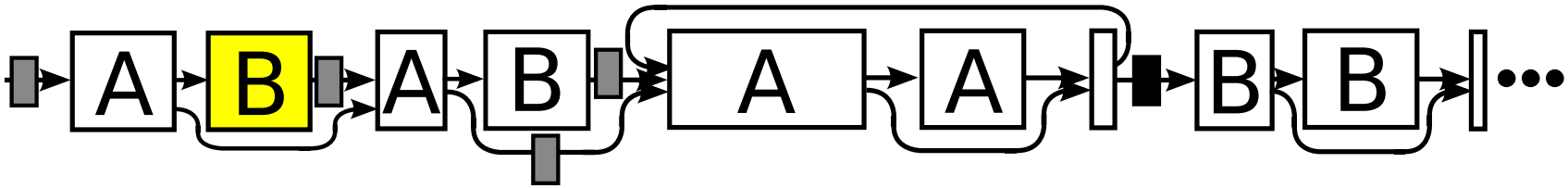


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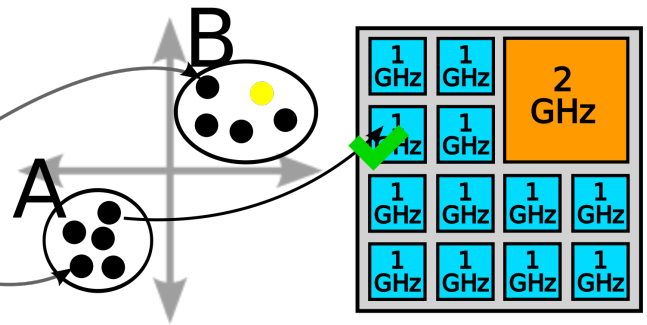
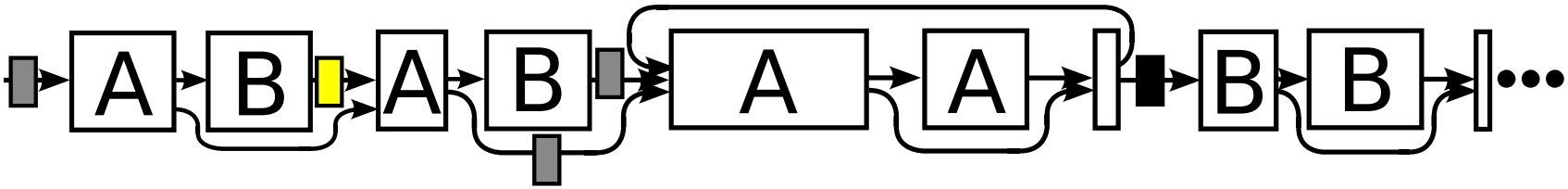


Dynamic: Monitor

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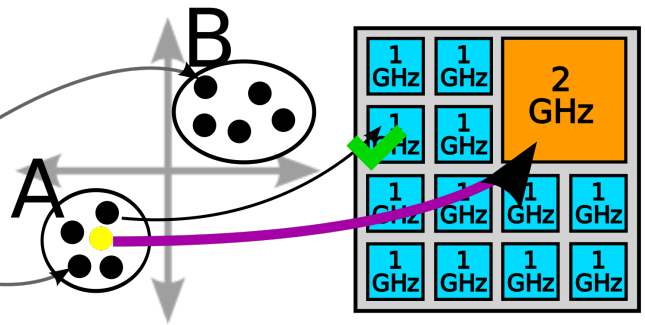

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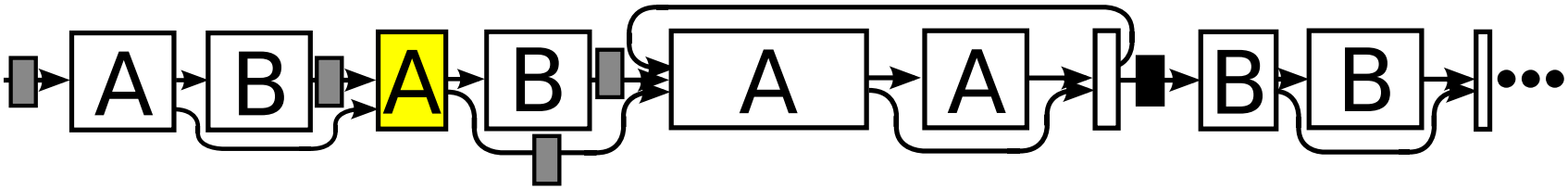


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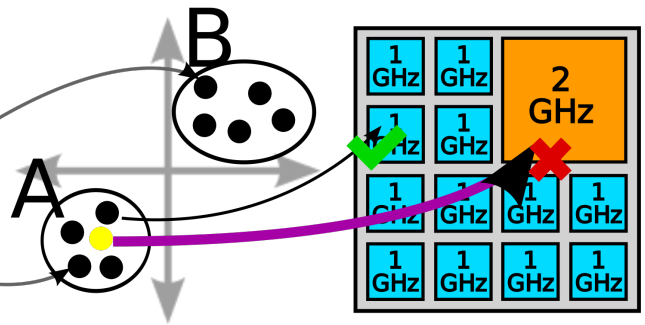
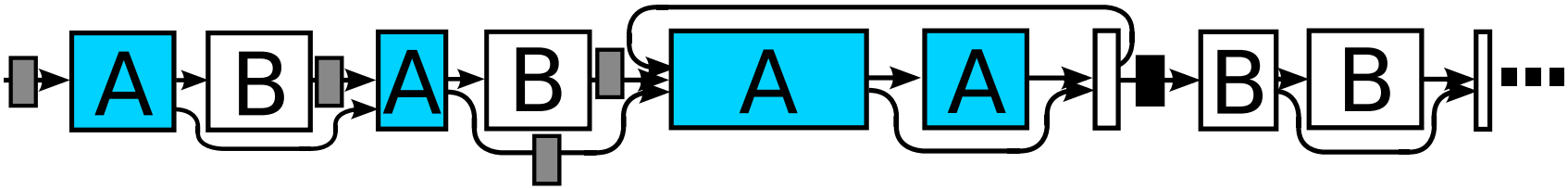


Dynamic: Determine preferred core

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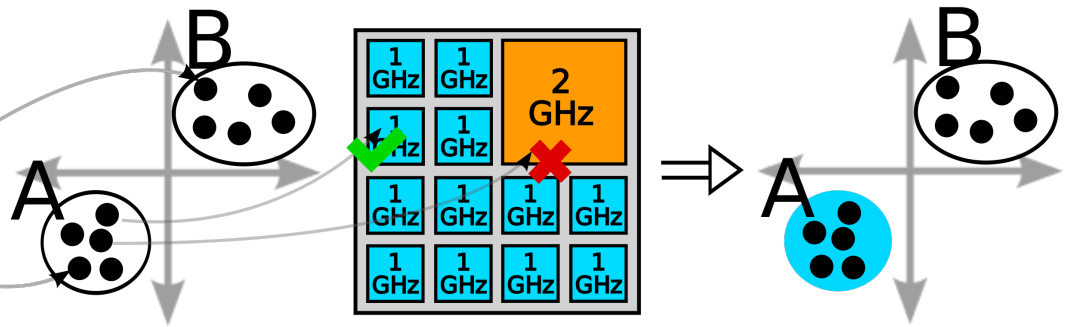

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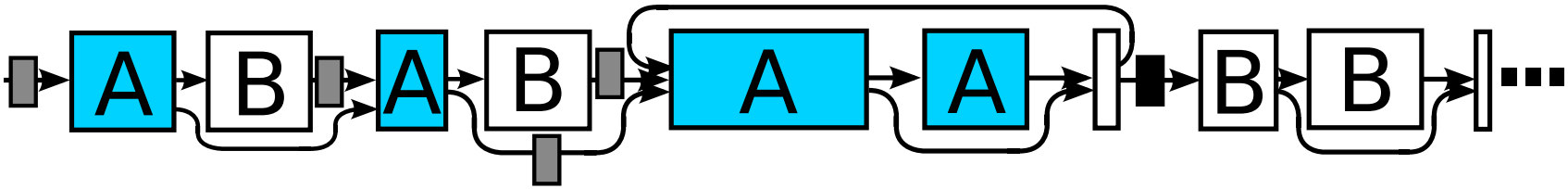


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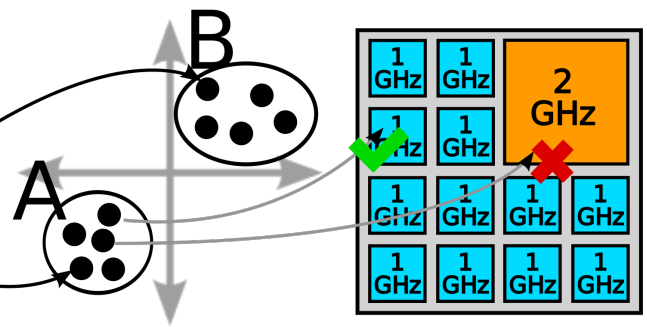

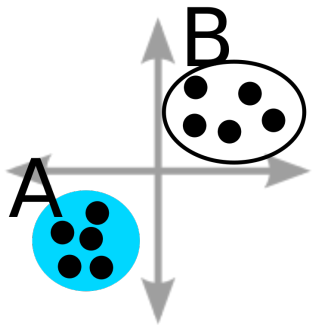


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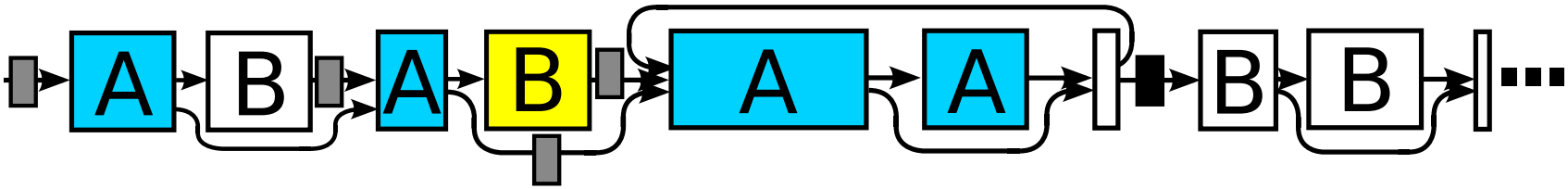
Dynamic: Run

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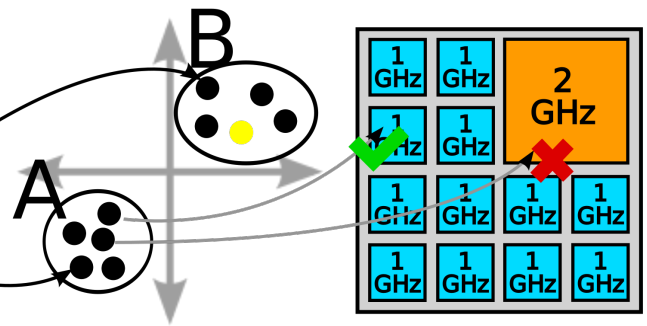

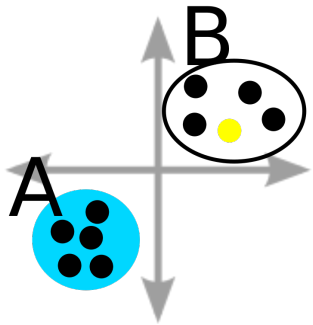


```
void foo(){
  opt(B)
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  //cpu intense
  opt(A)
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```
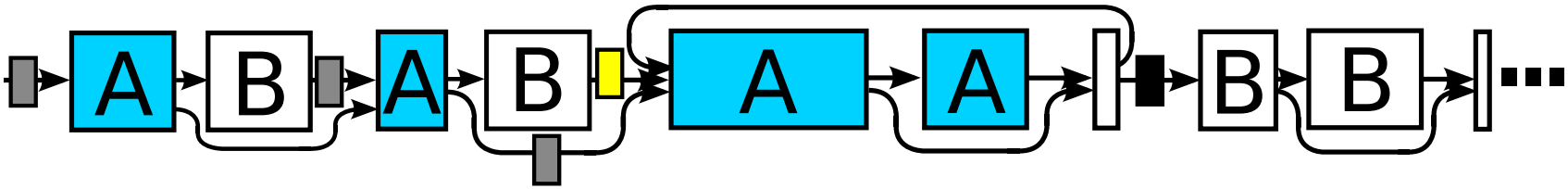

Dynamic: Switch to matched core (slow)

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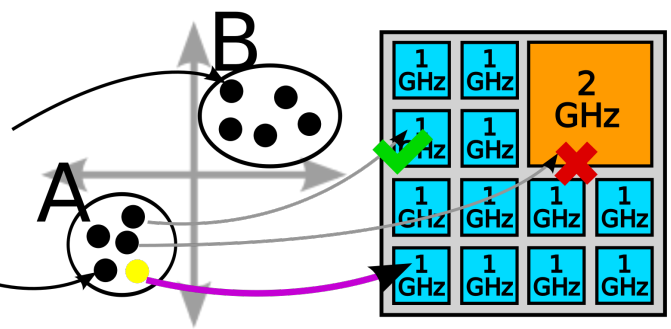

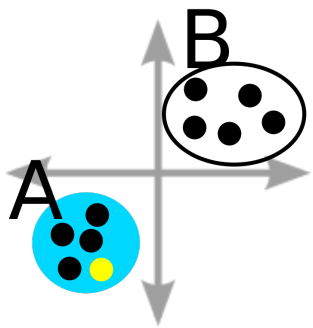


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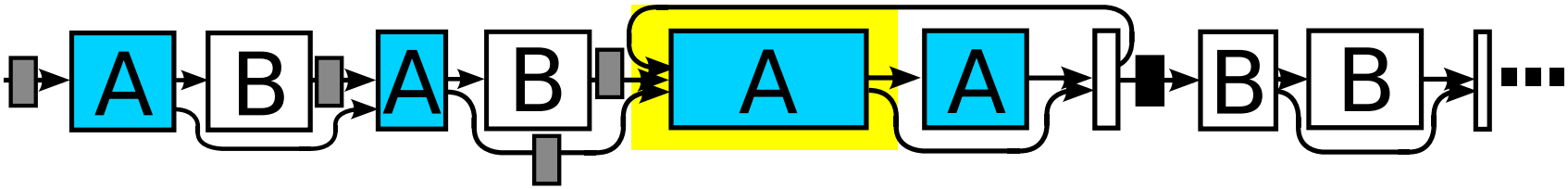
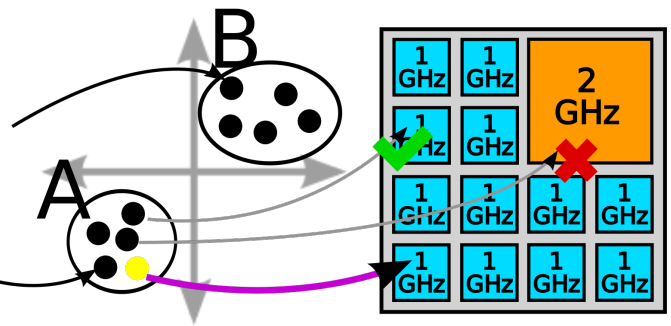
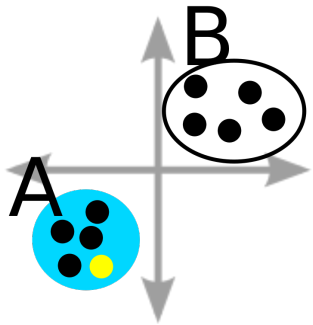
```

Dynamic: Run on matched core (slow)




```
void foo(){
  for(i=0:n)
  //cpu intense
  for(i=0:n)
  //mem intense
}
```



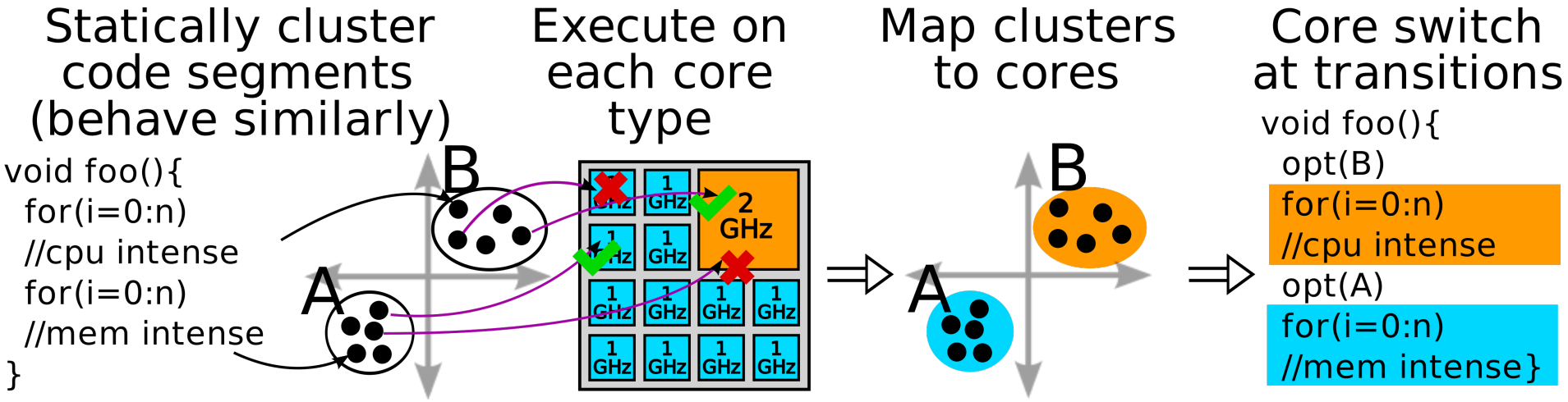



```
void foo(){
  opt(B)
  for(i=0:n)
  //cpu intense
  opt(A)
  for(i=0:n)
  //mem intense}
```

Solution overview

Hybrid analysis – phase-guided tuning

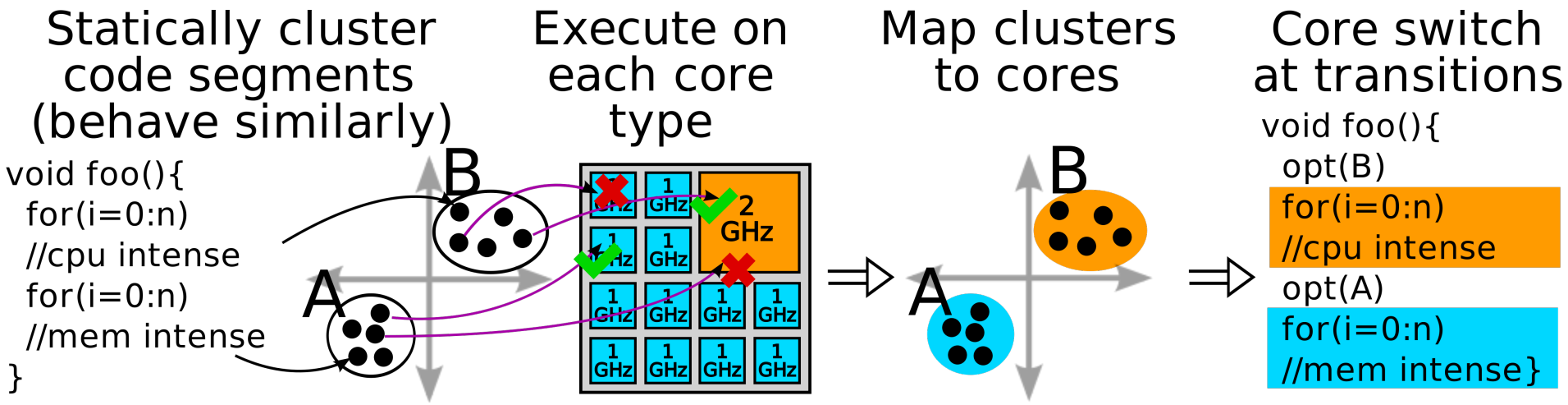
- Statically predict approximate similarity



Solution overview

Hybrid analysis – phase-guided tuning

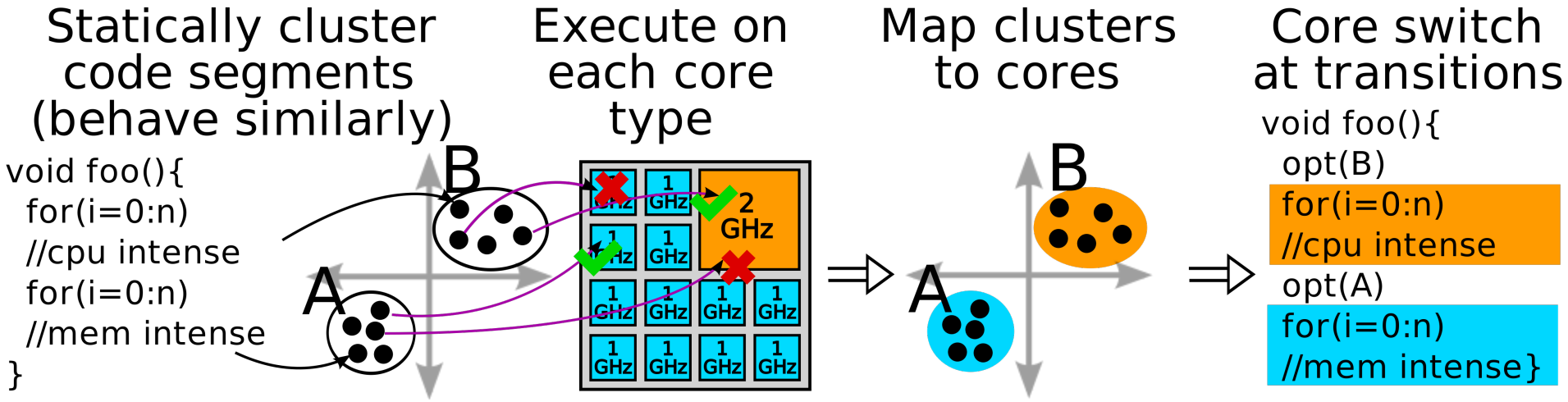
- Statically predict approximate similarity
- Statically instrument application with this information
  - Find likely phase transitions (structures with different types)
  - Instrument paths into likely long running code (e.g. loops)



Solution overview

Hybrid analysis – phase-guided tuning

- Statically predict approximate similarity
- Statically instrument application with this information
  - Find likely phase transitions (structures with different types)
  - Instrument paths into likely long running code (e.g. loops)
- Behavior of a section gives insight into entire cluster



Experimental Setup

- Hardware setup: Quad Core - 2x2.4GHz, 2x1.6GHz
- Workloads
  - 18-84 SPEC CPU2000 and CPU2006 benchmarks
  - constant workload size
- Compare to standard Linux assignment

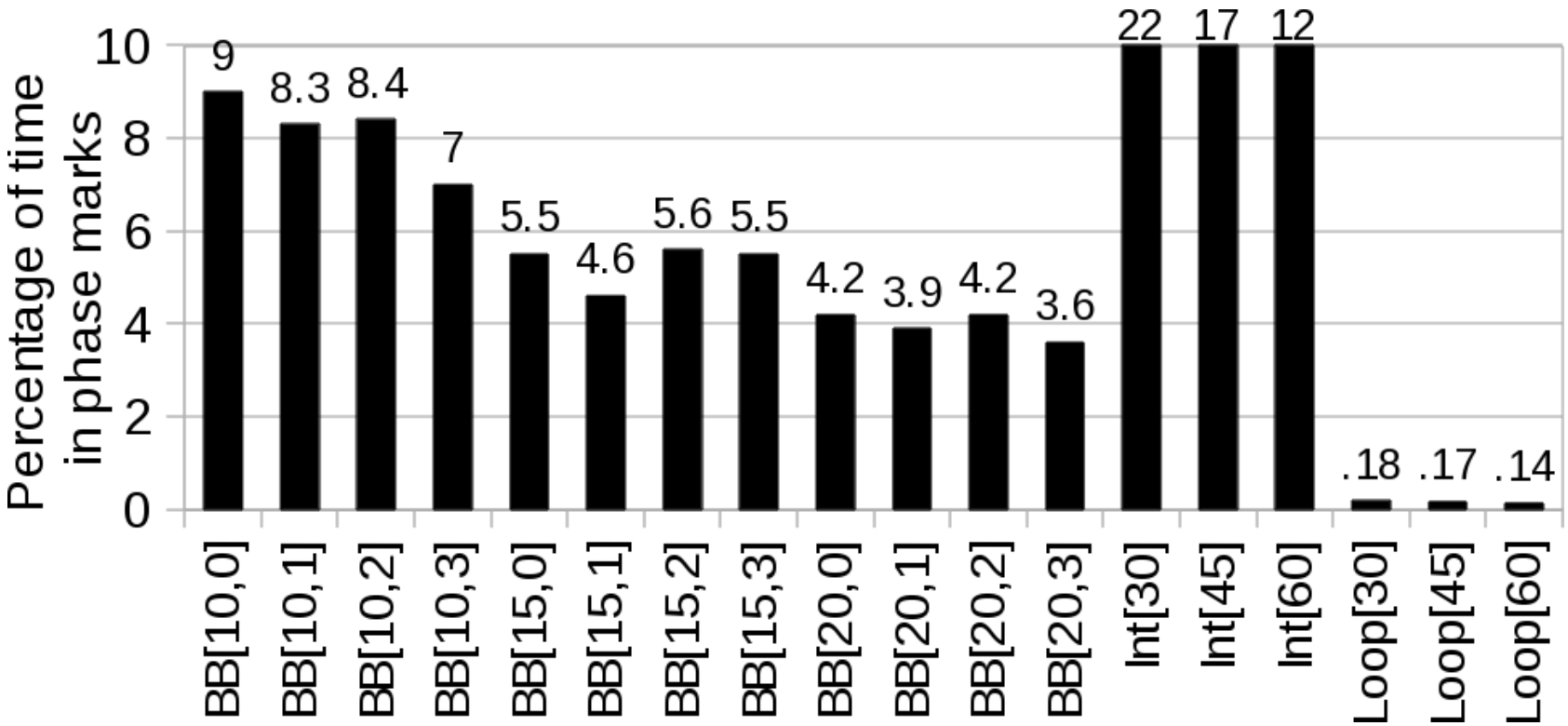
Overhead

- Space overhead
- Time overhead
- Average cycles per switch

Time Overhead

- Time overhead
  - Time spent executing code in phase marks
  - Directly impacts performance

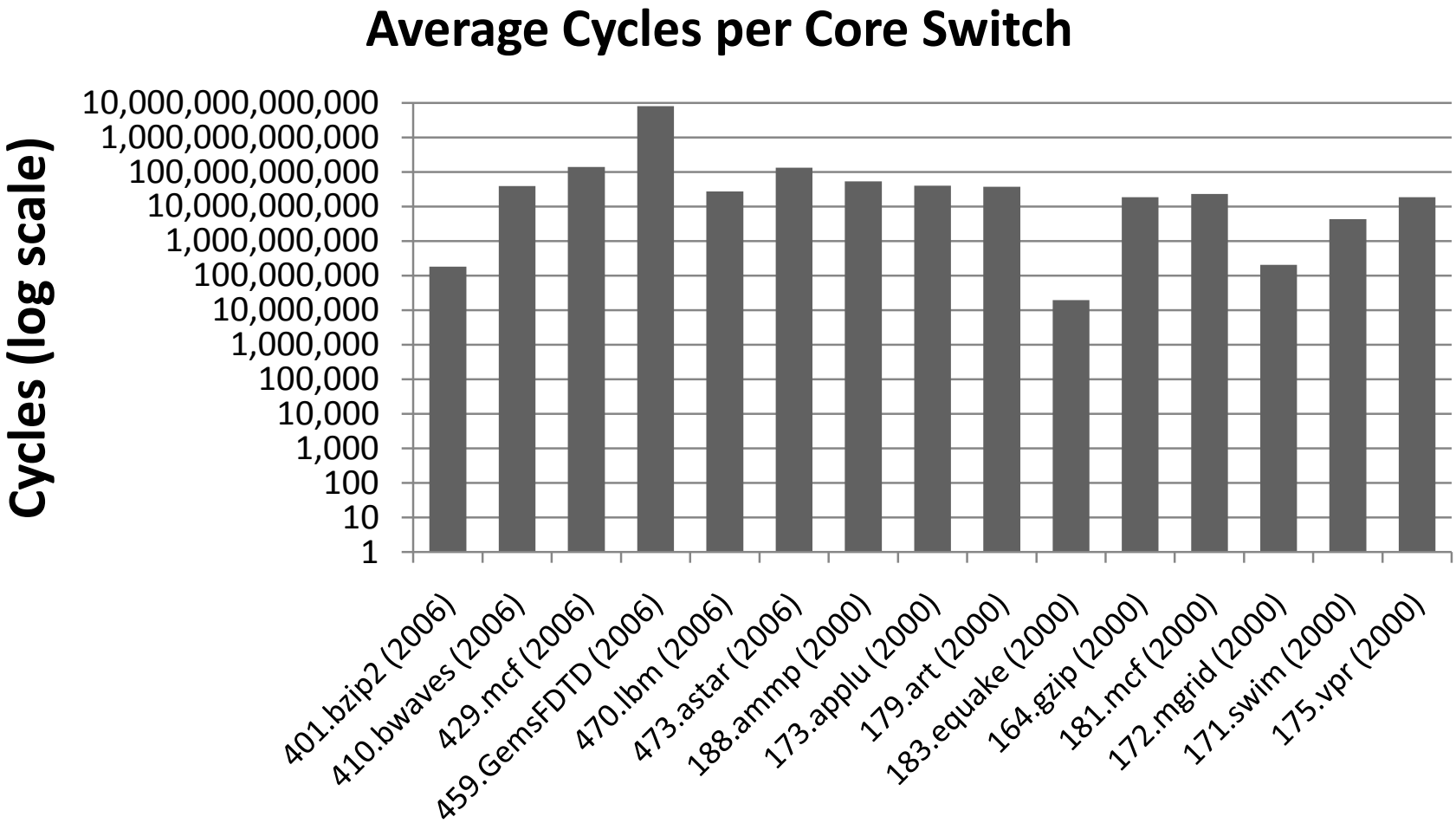
Time Overhead



Cycles per Switch

- Average cycles per switch
  - Impacts performance
  - Must be high enough to amortize runtime costs

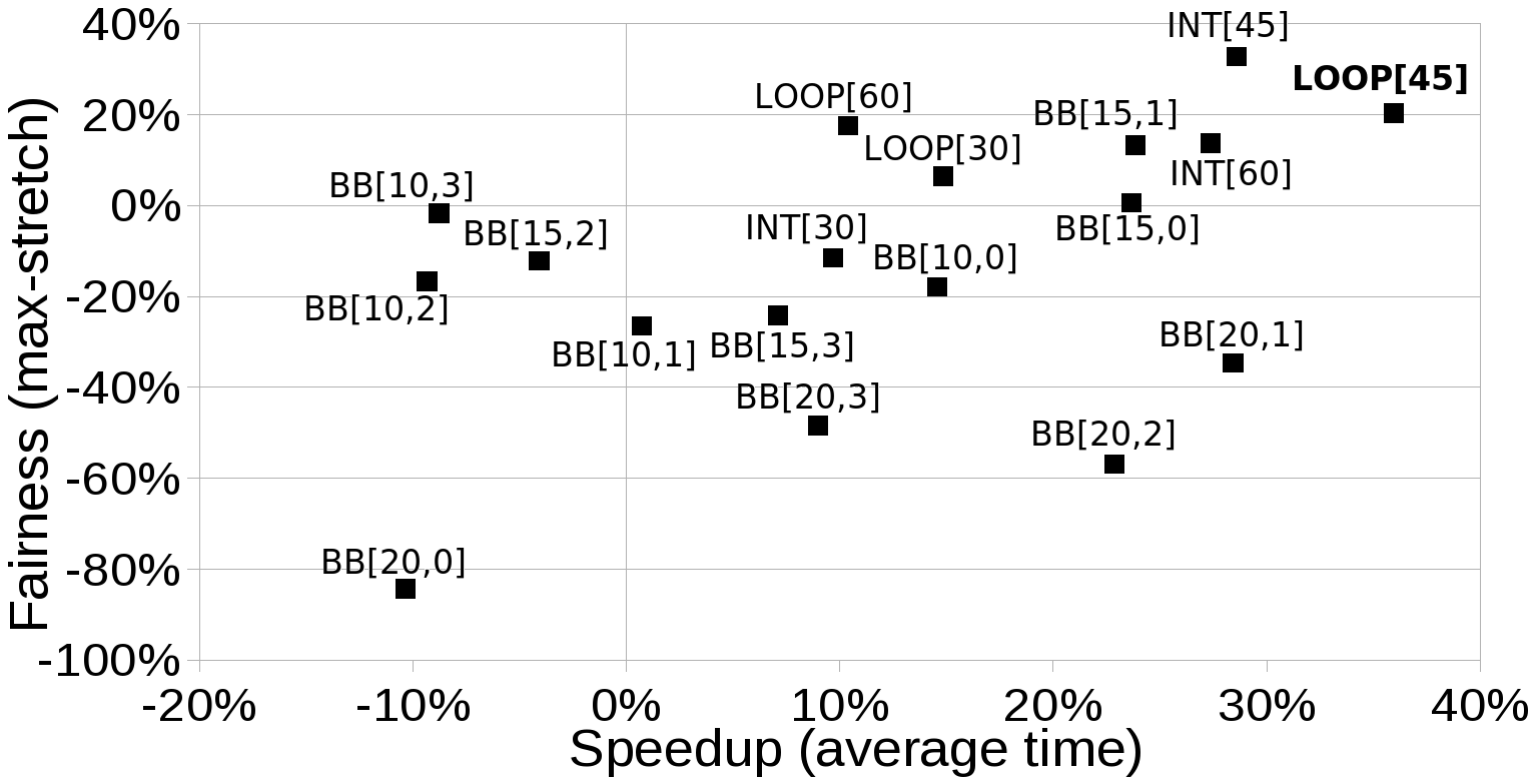
Cycles per Switch



Performance

- Speedup – average process time
- Fairness (max-stretch) – maximum process slow-down

Speedup vs Fairness



Best: Inter-procedural loop technique, min. size 45 instructions

Future Work

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- Improved techniques for picking phase marks

  e.g. estimate number of iterations instead of number of instructions

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- Improve static behavior similarity prediction
- Improved techniques for picking phase marks

  e.g. estimate number of iterations instead of number of instructions
- Dynamic optimization
  - feedback mechanism to improve assignment
  - globally optimal assignment

Conclusion

- Performance asymmetric multicores are beneficial
- Problem: Techniques to effectively utilize are needed
- **Idea: Use repeating behavior to reduce dynamic overhead.**

Conclusion

- Performance asymmetric multicores are beneficial
- Problem: Techniques to effectively utilize are needed
- **Idea: Use repeating behavior to reduce dynamic overhead.**
  - Programmer oblivious – behavior and architectures
  - Automatic – requires no assistance from programmer
  - Negligible overhead – less than 0.2% runtime overhead
  - Transparent deployment – no OS or compiler modification
  - Tune once run anywhere – architecture independent

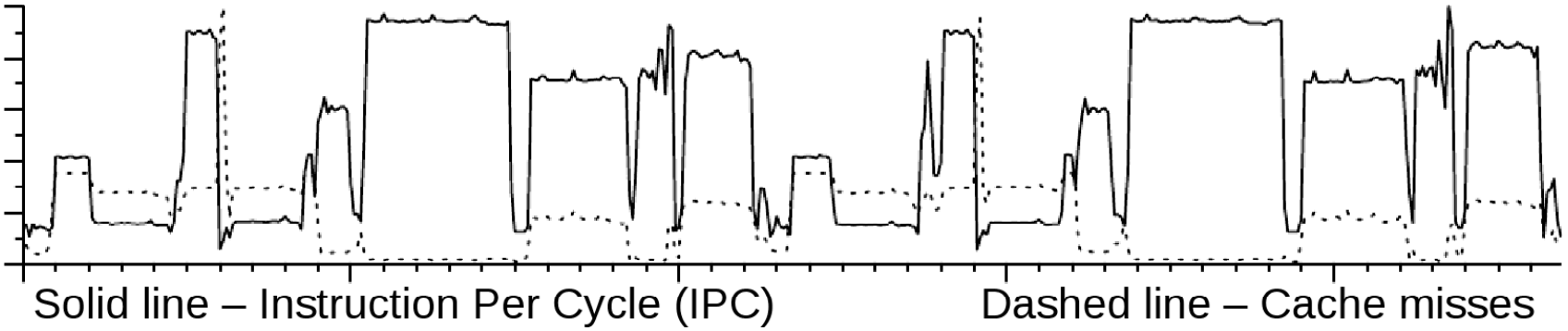
Questions

Questions?

Idea

Problem: Match code to cores based on resources needed/provided

- **Behavior:** resource requirements (IPC, cache miss, etc.)
- **Phase:** segment of execution with similar behavior throughout[3]
- **Insight**: Behavior tends to repeat itself.



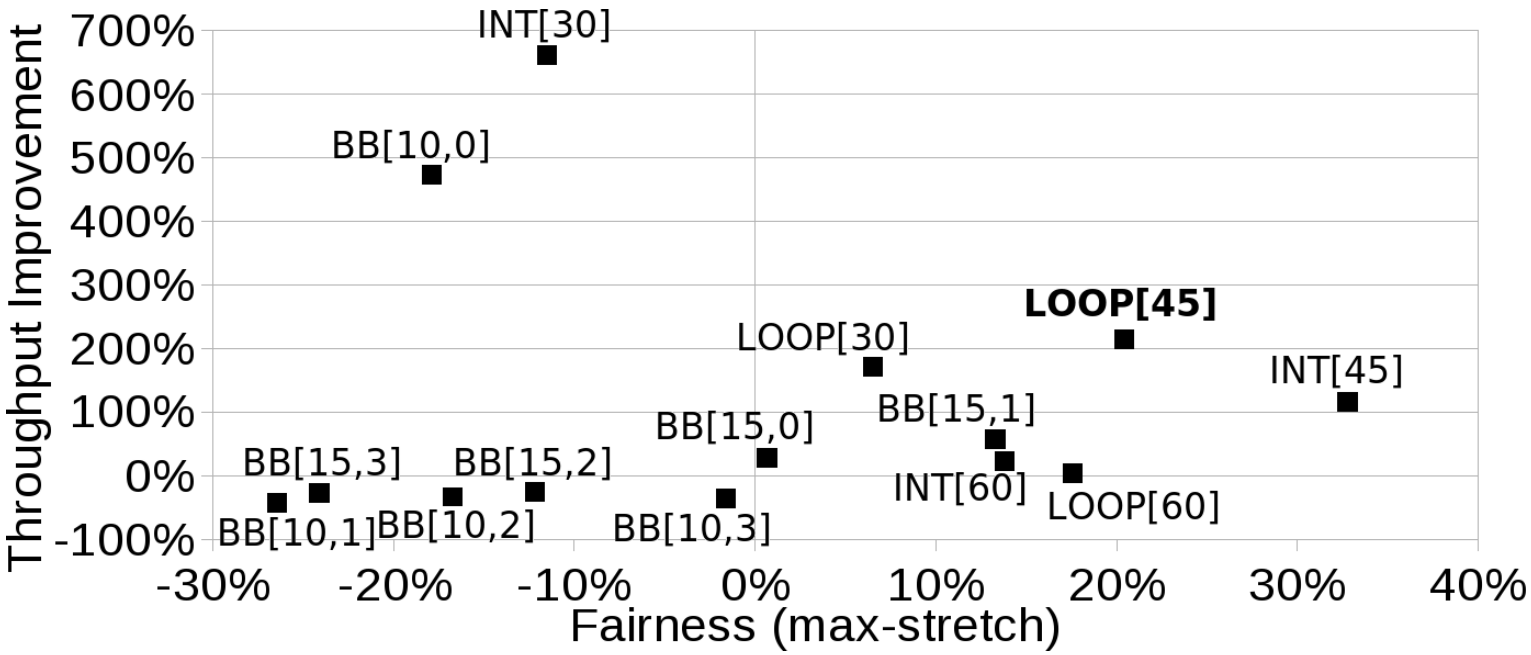
Phase behavior for gcc (taken from [3]) 5

[3] T. Sherwood et al. ASPLOS '02

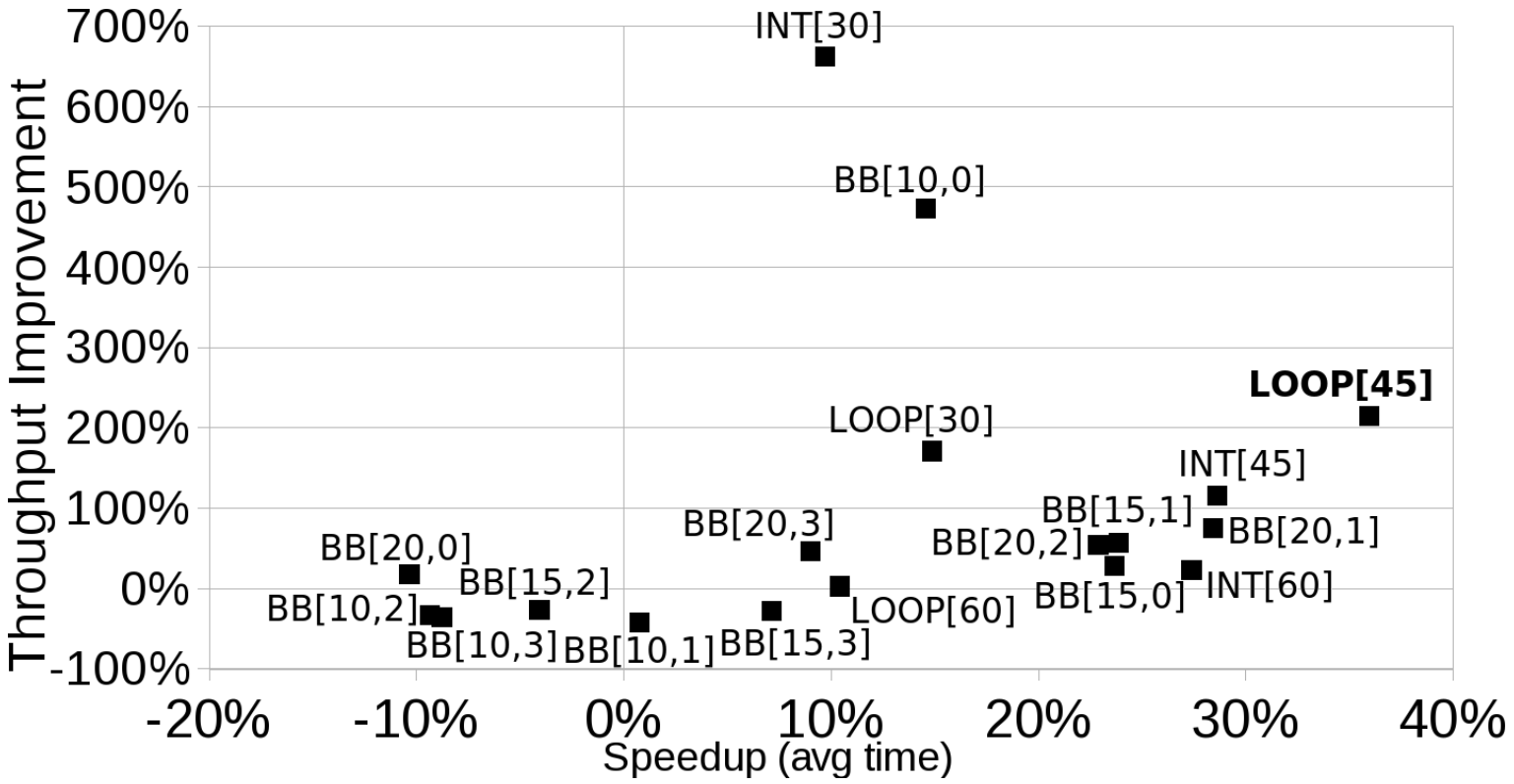
Experimental Setup

- Hardware setup: Quad Core - 2x2.4GHz, 2x1.6GHz
- Software setup
  - Static analysis/instrumentation: our framework based on GNU Binutils
  - Runtime Performance monitoring: PAPI, perfmon2
  - Core switching: affinity calls built-in to kernel
  - Workloads
    - 18-84 SPEC CPU2000 and CPU2006 benchmarks
    - constant workload size
- Compare to standard Linux assignment

Throughput vs Fairness



Speedup vs Throughput



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Determining program behavior

Falls into two categories

- Techniques using execution traces
- Purely dynamic techniques

Execution Traces

- Benefits:
  - Very accurate since actual performance is known
  - Low dynamic overhead since no monitoring is required
- Limitations:
  - Requires sample input set to be developed
  - Run entire program to create execution trace
  - What about sections of code not covered by sample input?
  - Do different inputs result in different behavior?

Purely Dynamic

- Benefits:
  - Does not require sample input sets
  - No need for execution trace
  - Does not monitor the whole program
- Limitations:
  - Decisions for future code are made based on past code
  - Higher dynamic overhead since we must monitor periodically throughout the entire execution

Phase Marking cost

Recall that we had two problems to solve:

- Move work from dynamic to static analysis – phase-guided
- Reduce number of / pick good instrumentation points

Phase Marking cost

Recall that we had two problems to solve:

- Move work from dynamic to static analysis – phase-guided
- Reduce number of / pick good instrumentation points

Phase Marking cost

- Phase marks cost (space and run-time)
- We need techniques to pick good insertion points
  - Basic block
  - Basic block with look-ahead
  - Interval (intra-procedural)
  - Loop (inter-procedural)

5

Basic Block

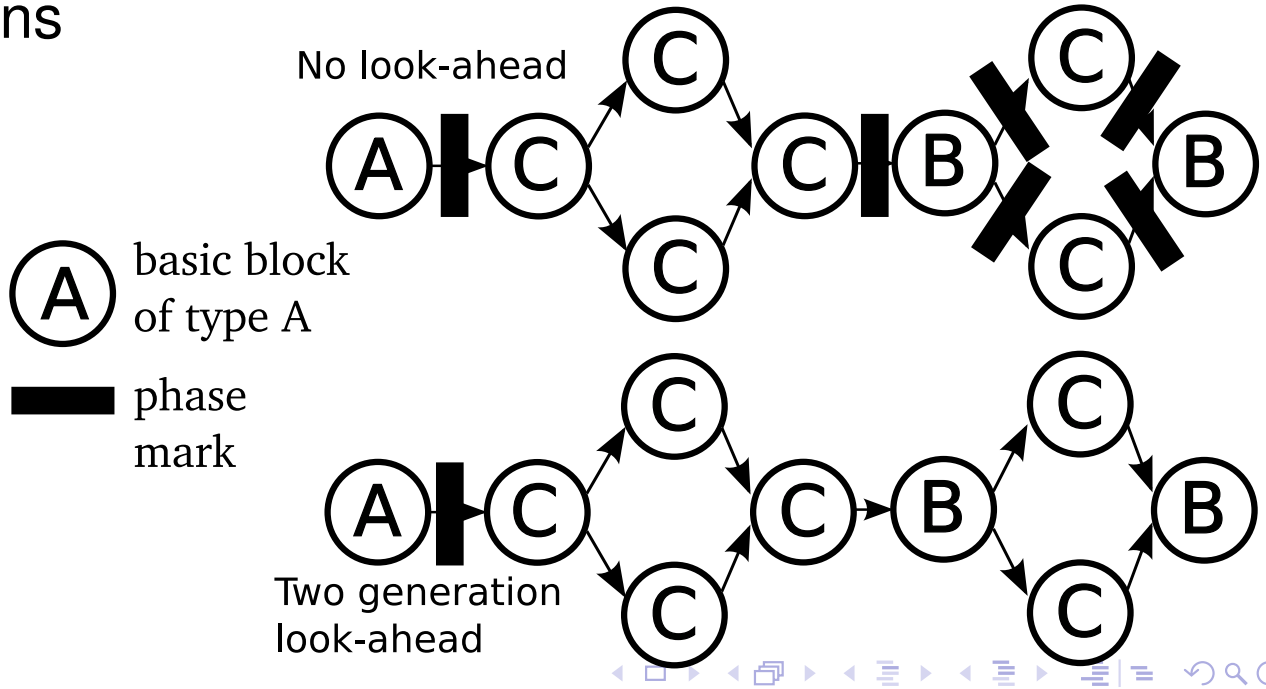
Basic block

- Similarity is done on basic blocks
- Transitions between blocks with different types
- Problem: blocks are small, cost is likely higher than gains

Basic Block with Look-ahead

Basic block with look-ahead

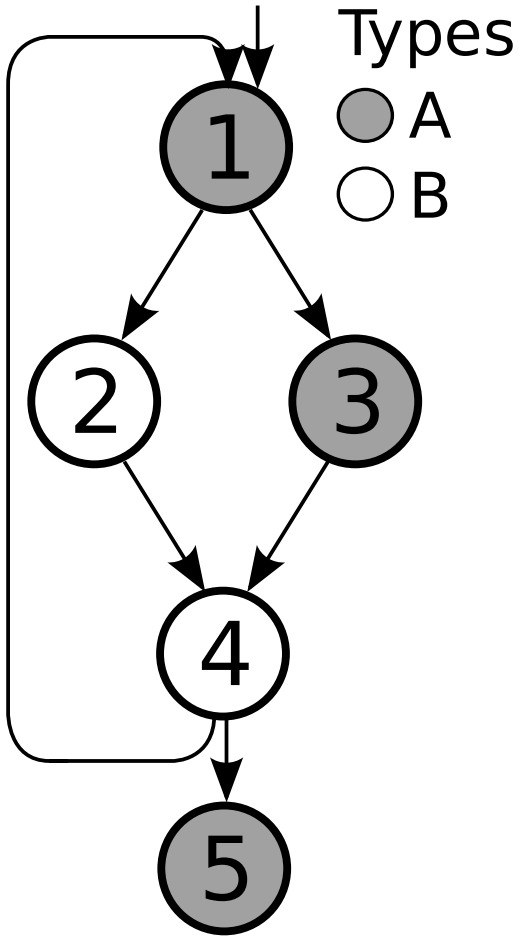
- Instrument if next ***n*** blocks are of similar type
- Ensures switching for larger number of instructions
- In some cases, captures loops
- Problem: allows multiple switches in small loops
- Problem: cost of optimizing a few blocks is still likely to overshadow gains



Intervals

Interval (intra-procedural)

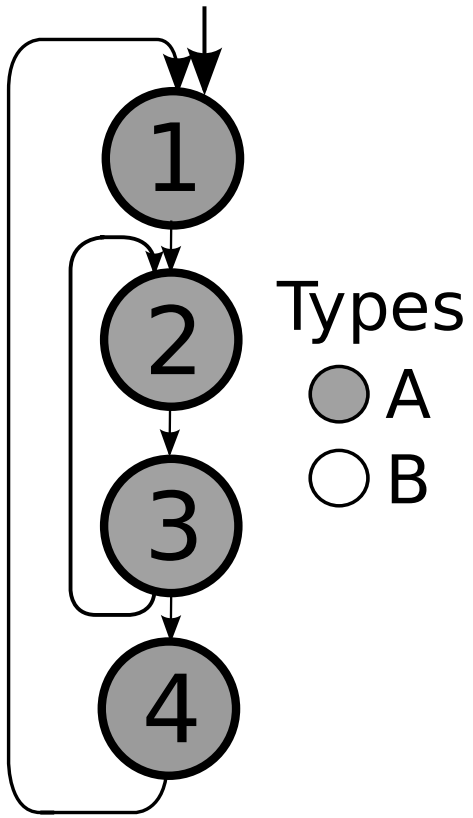
- Instrument if interval has a predominant type
- Intervals capture small loops
- All instructions are part of some interval
- Problem: some intervals are not loops (few instructions)



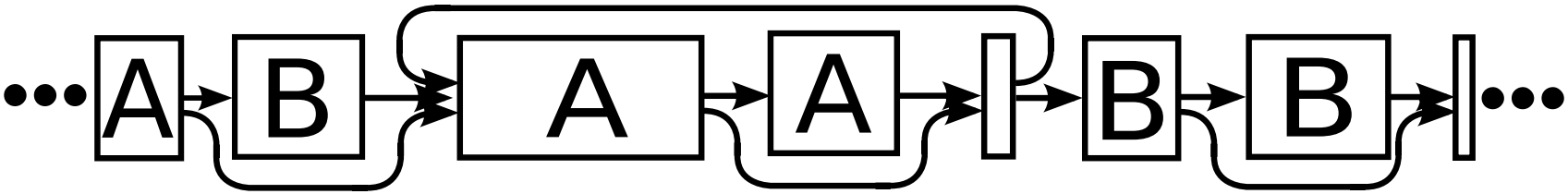
Loop

Loop based (inter-procedural)

- Instrument loop based on predominant type
- Remove instrumentation if part of larger loop of same type
- Captures loops and nothing else
- Considers nested loops
- Considers function calls



Static: Determine approximate similarity




```
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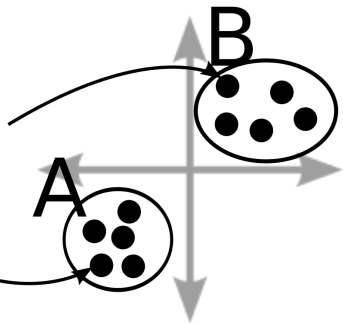

Static: Predicting Similarity

- Not predicting actual behavior, just similarity
- Various metrics to consider
  - **instruction mix** (int vs float, div, etc)
  - **cache behavior**
  - branch prediction accuracy
  - available ILP
  - data structure(s)
- Proof-of-concept: 85% accuracy using few metrics

Space overhead

- Space overhead
  - May hurt instruction cache performance
  - Increased binary file size

Space Overhead