SyncProf: Detecting, Localizing, and Optimizing Synchronization Bottlenecks

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Motivation

Challenge:

Synchronization bottlenecks

Photo: Jürgen Schoner

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Profiling tools:

Very limited

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Profiling tools:

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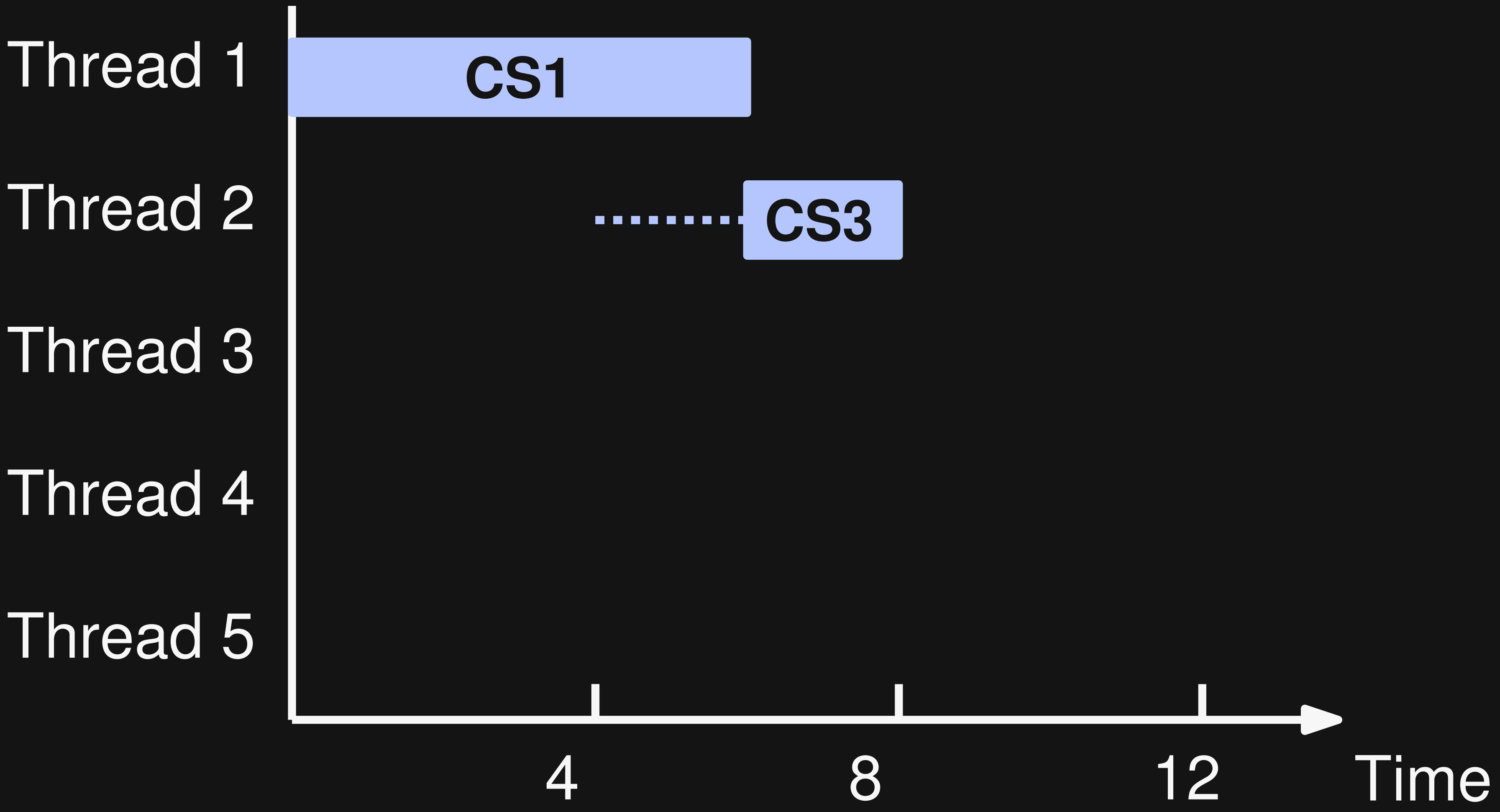
Finding, understanding, and fixing synchronization bottlenecks: Mostly manual

Example

Synchronization bottleneck in KVM/QEMU driver:



▪▪🟦 **.. critical section with time to obtain lock, colors = locks**

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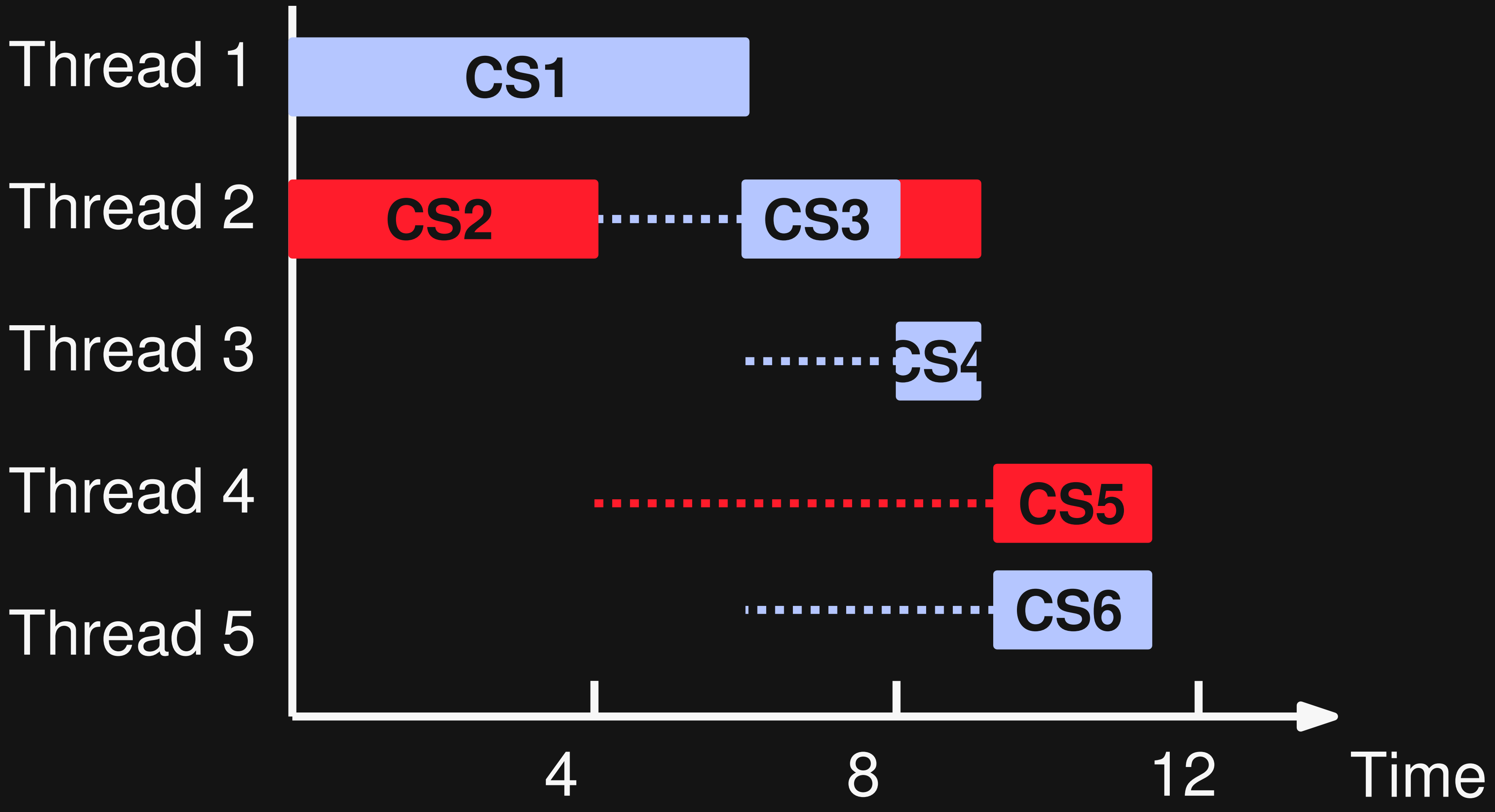

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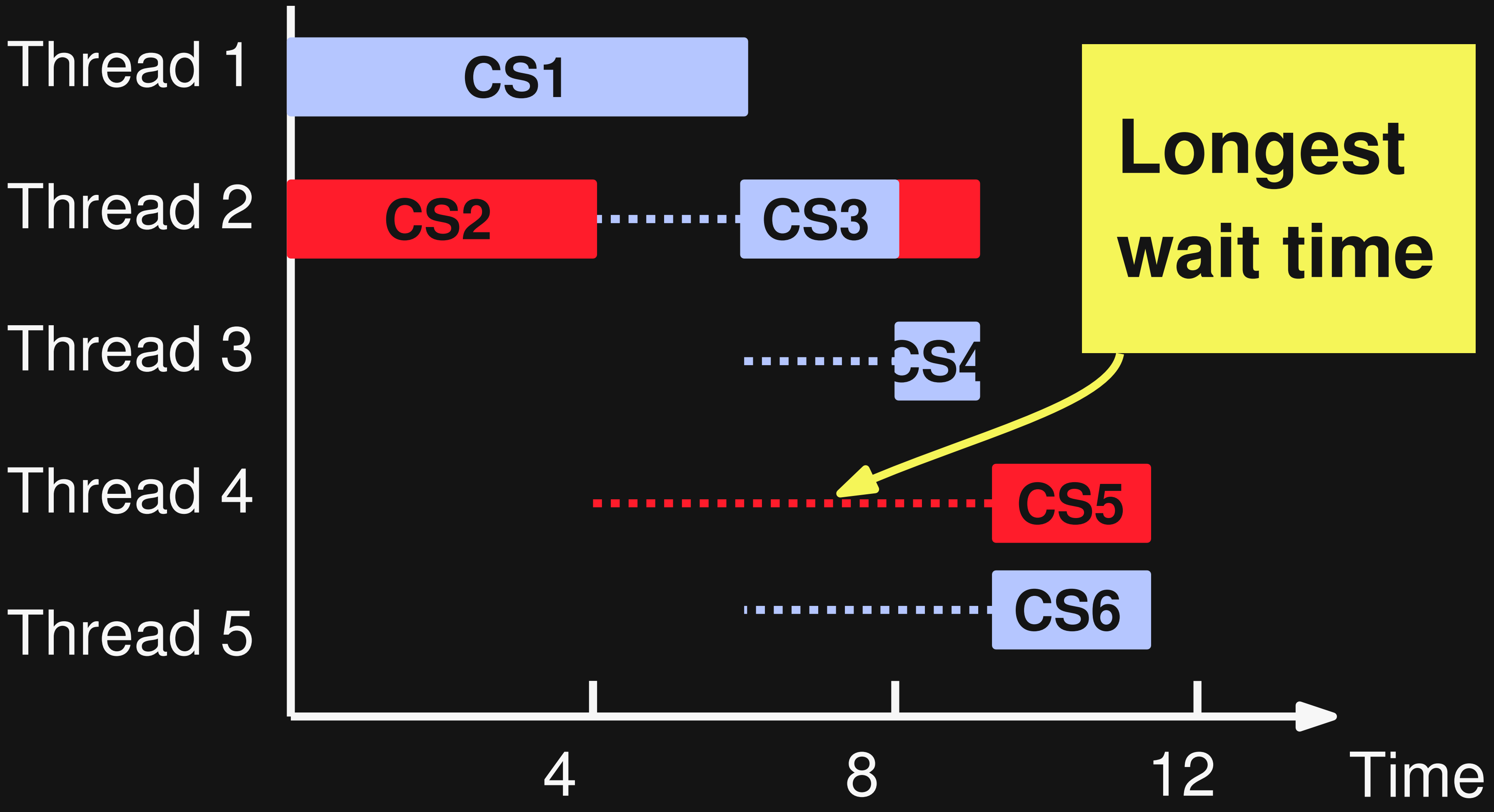

Longest wait time

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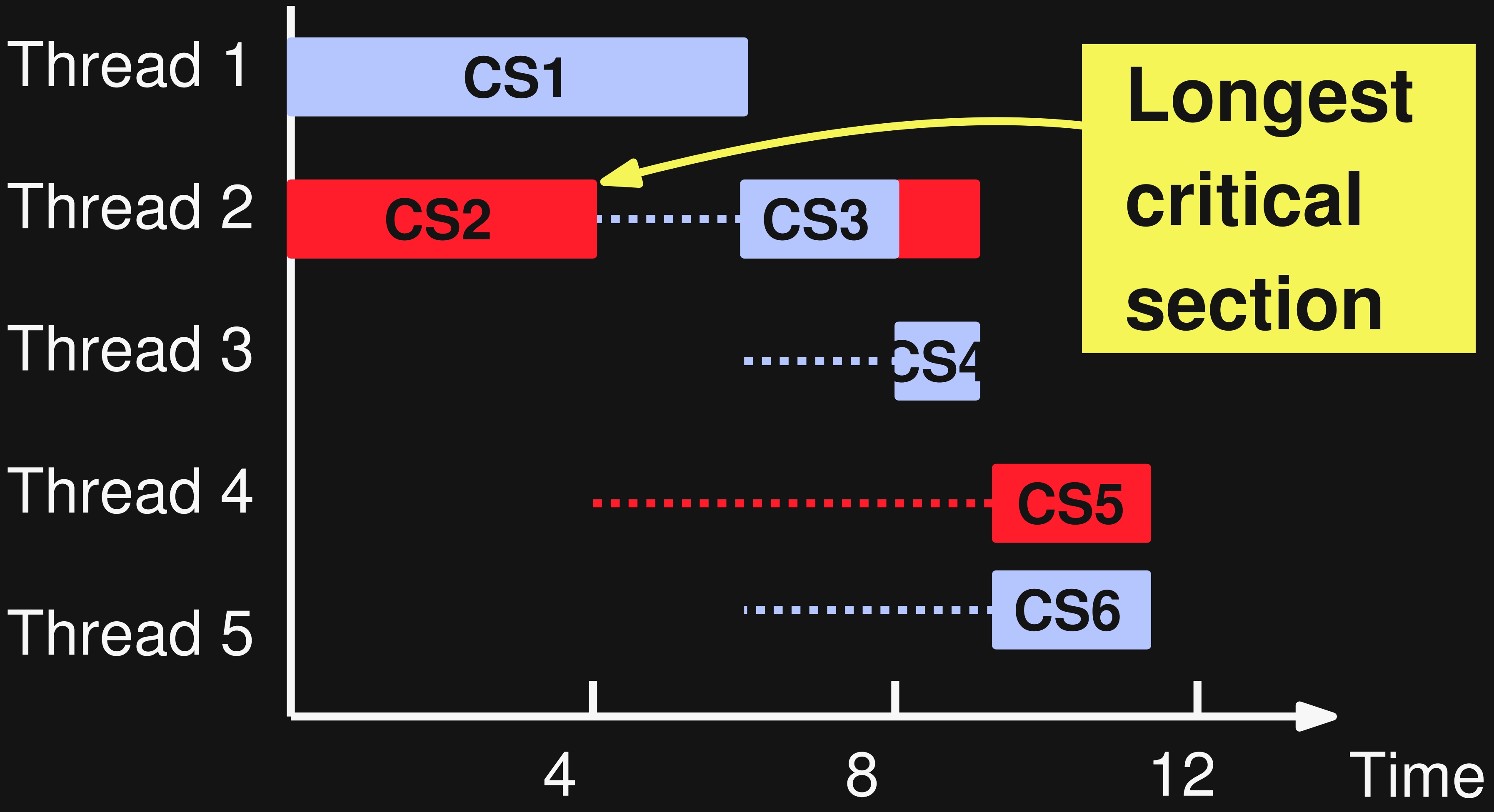

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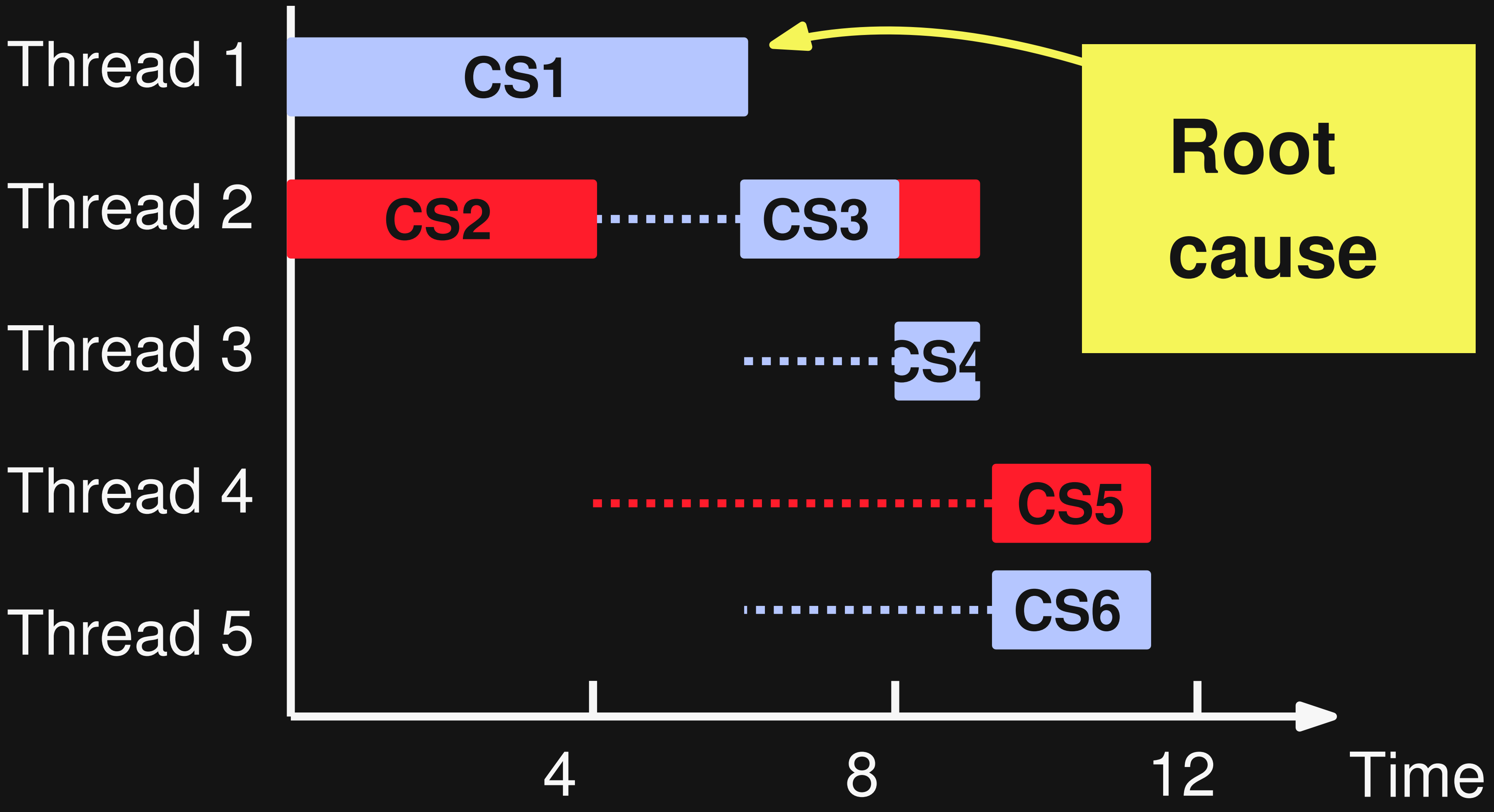

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Goals & Challenges

Find synchronization bottlenecks

Locate the root cause of a bottleneck

Help optimize the bottleneck

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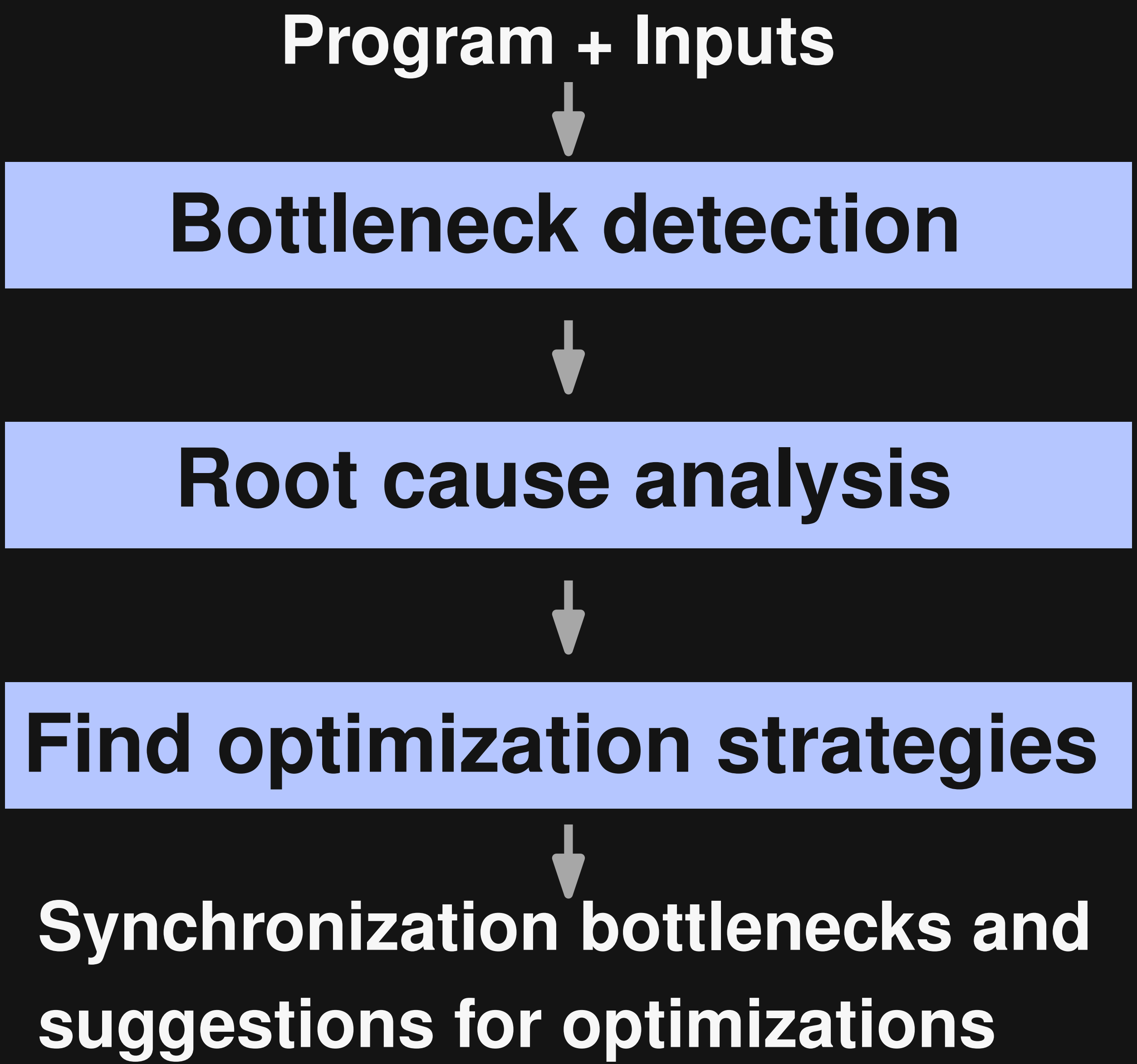
This talk: SyncProf

Actionable performance profiling for concurrent programs

Overview of SyncProf



Program + Inputs

Bottleneck detection

Root cause analysis

Find optimization strategies

Synchronization bottlenecks and suggestions for optimizations

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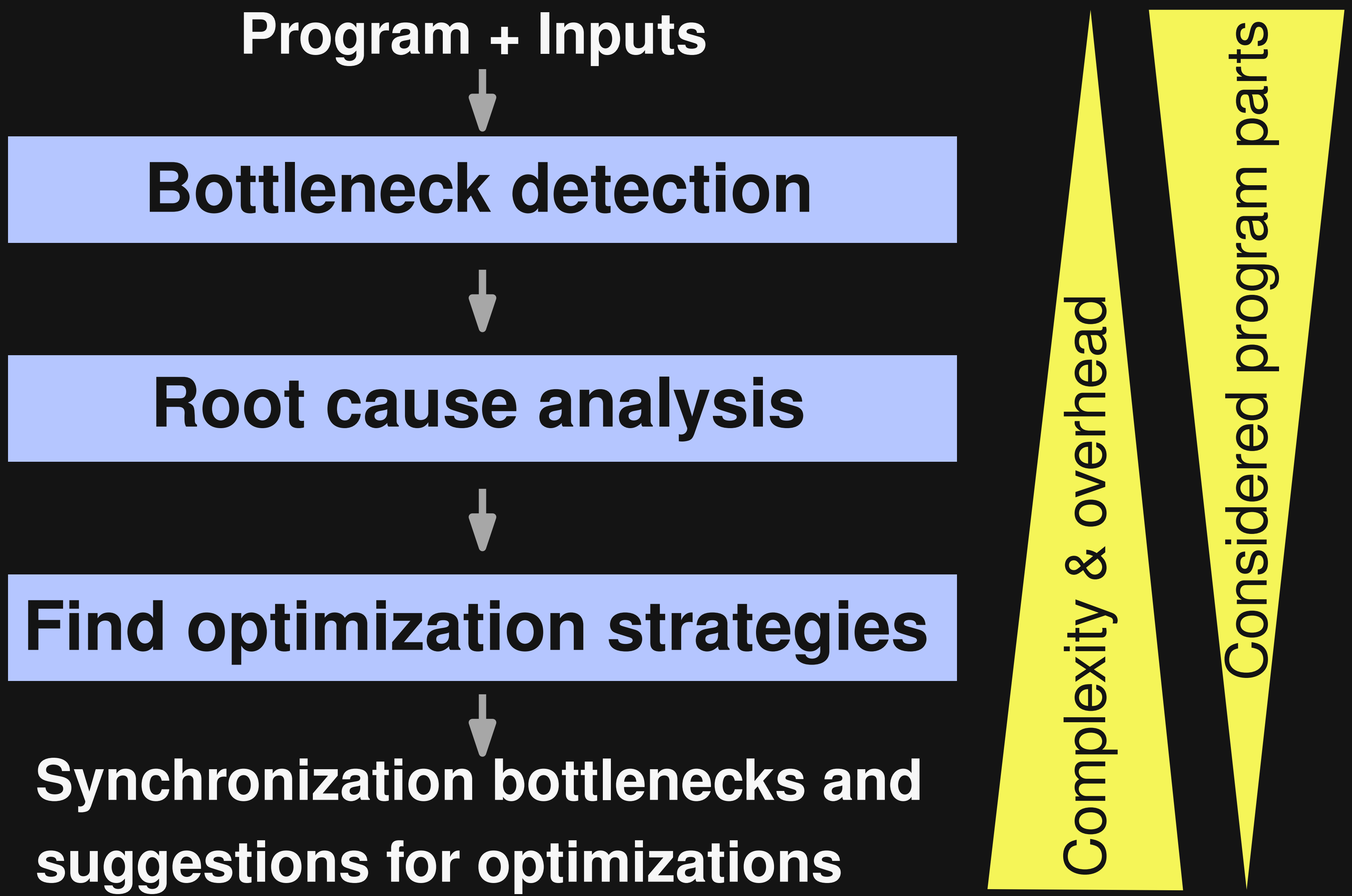

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Complexity & overhead

Considered program parts

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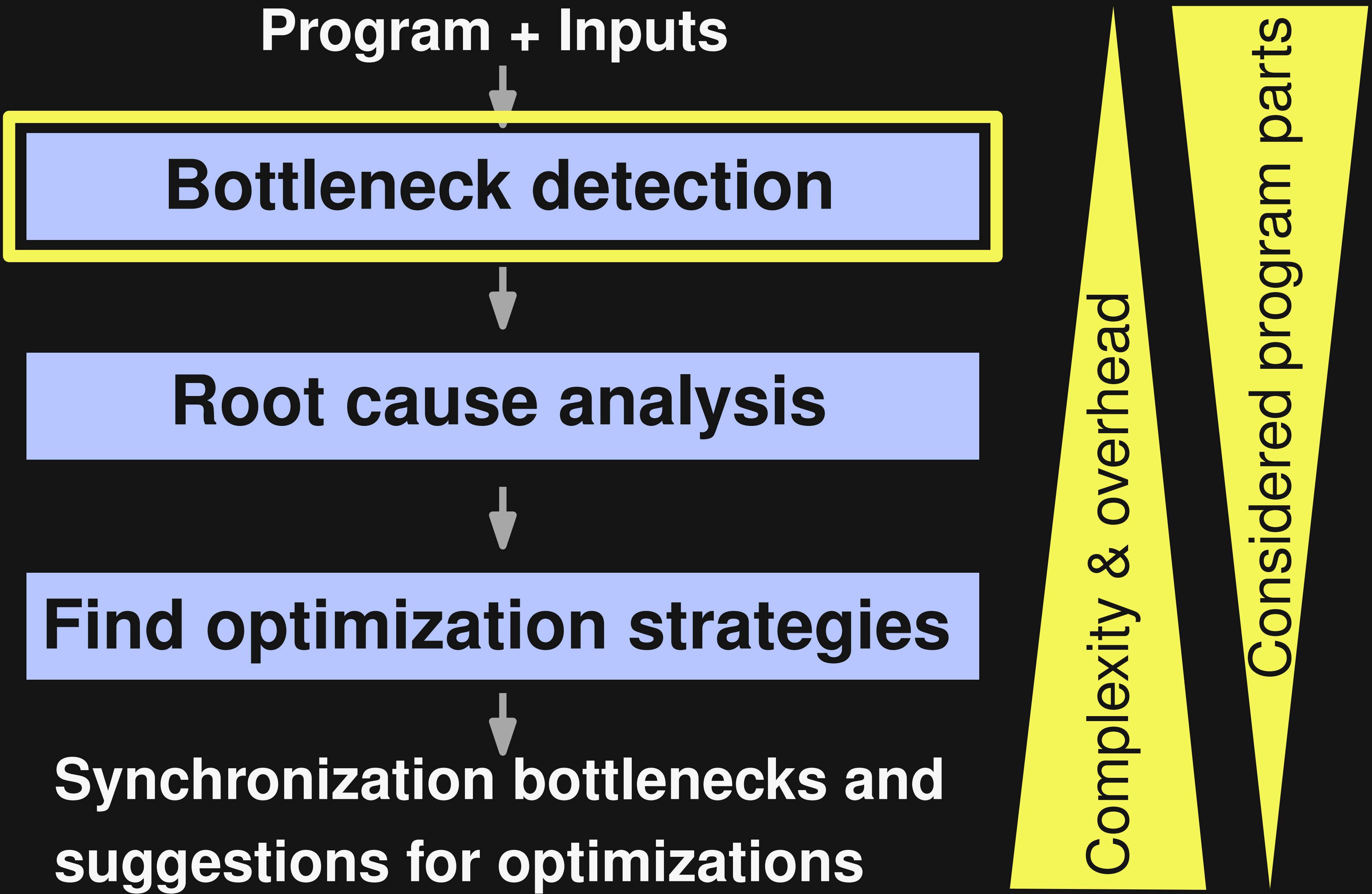

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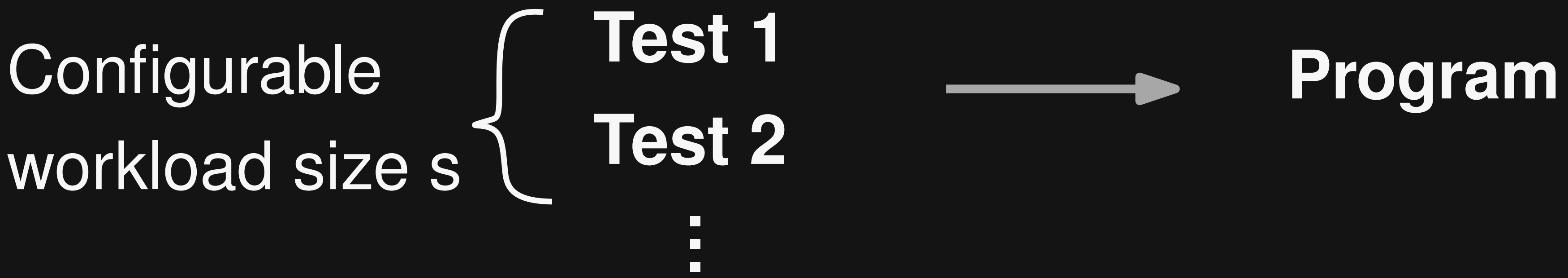
Find inputs that trigger synchronization bottlenecks



Configurable workload size s

Test 1

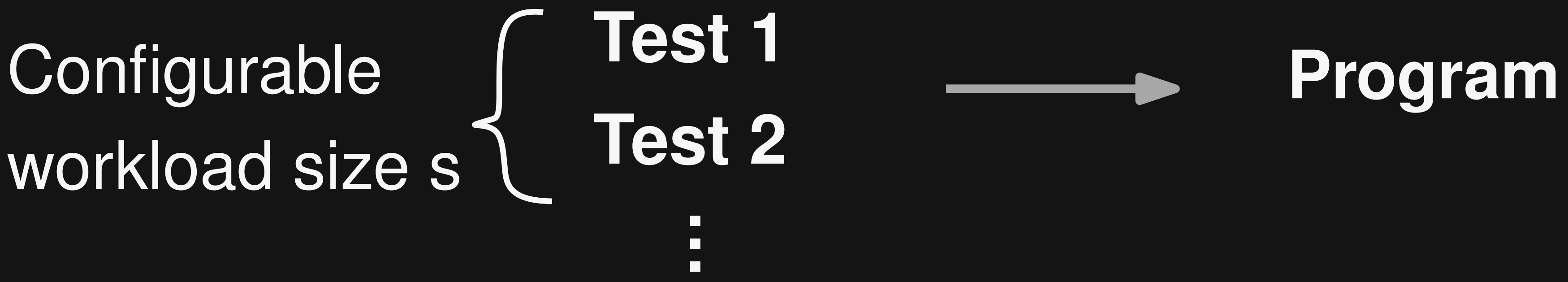
Test 2

⋮

Program

Bottleneck Detection

Find inputs that trigger synchronization bottlenecks



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Program

For each test t:

- **Execute t with increasing s**
- **If increase of s implies increase of execution time and CPU usage $<$ threshold: Keep t and s**

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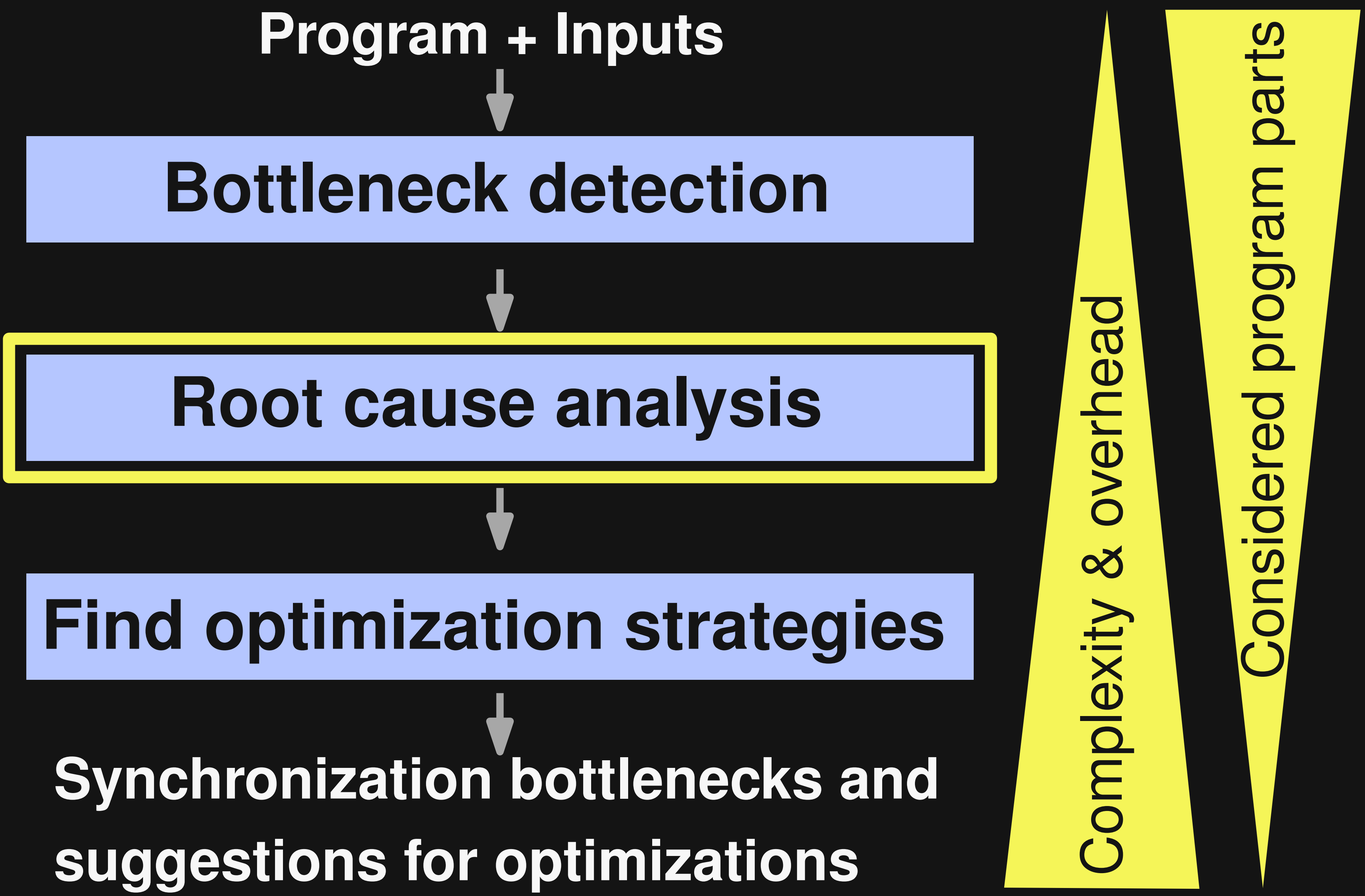

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Graph-based Root Cause Analysis

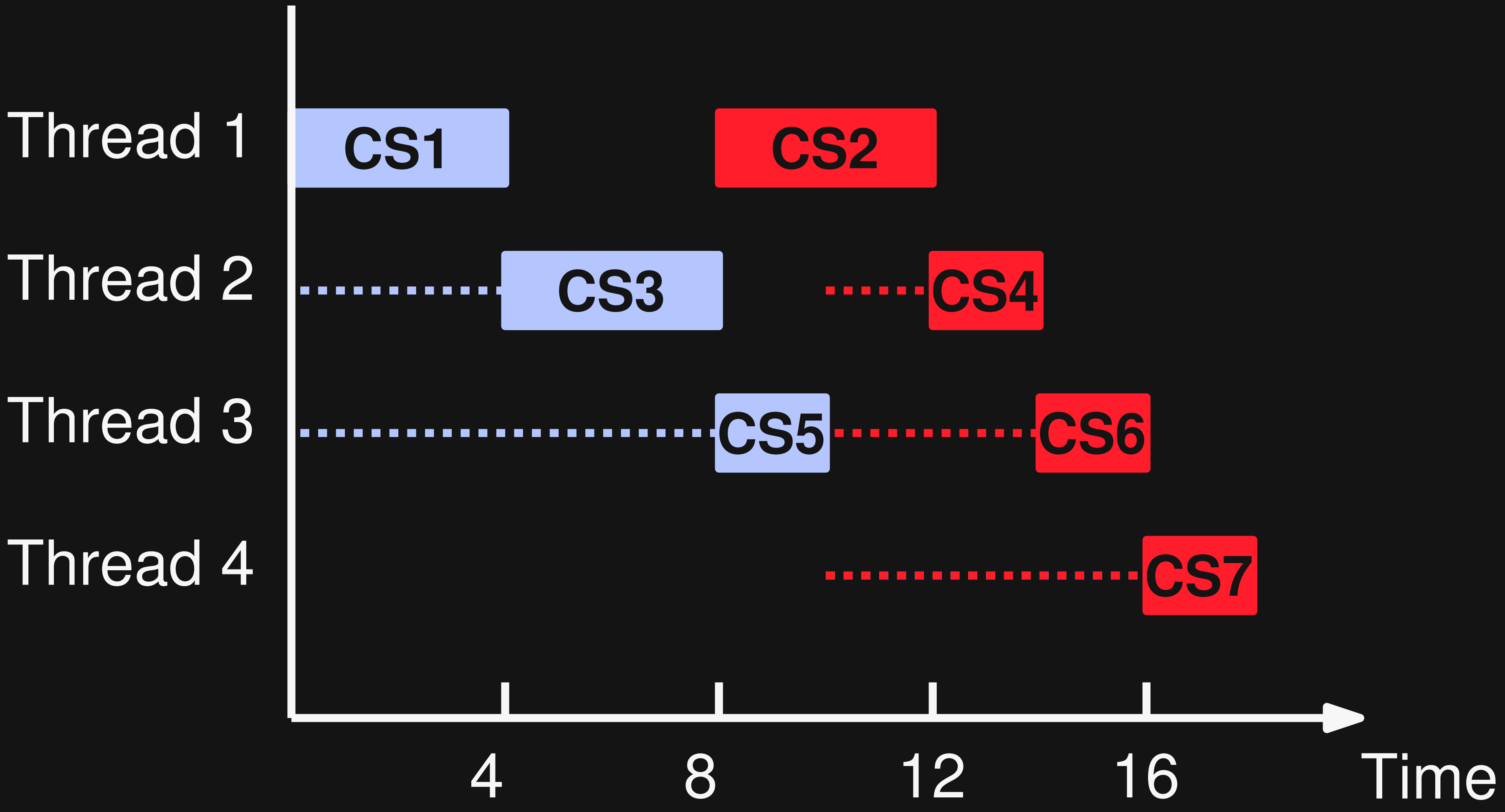
1) Summarize execution into graph

2) Analyze graph to find root cause

Synchronization dependence graph

- Nodes: Dynamic instances of critical sections
- Edges: Waits-for relations

Example



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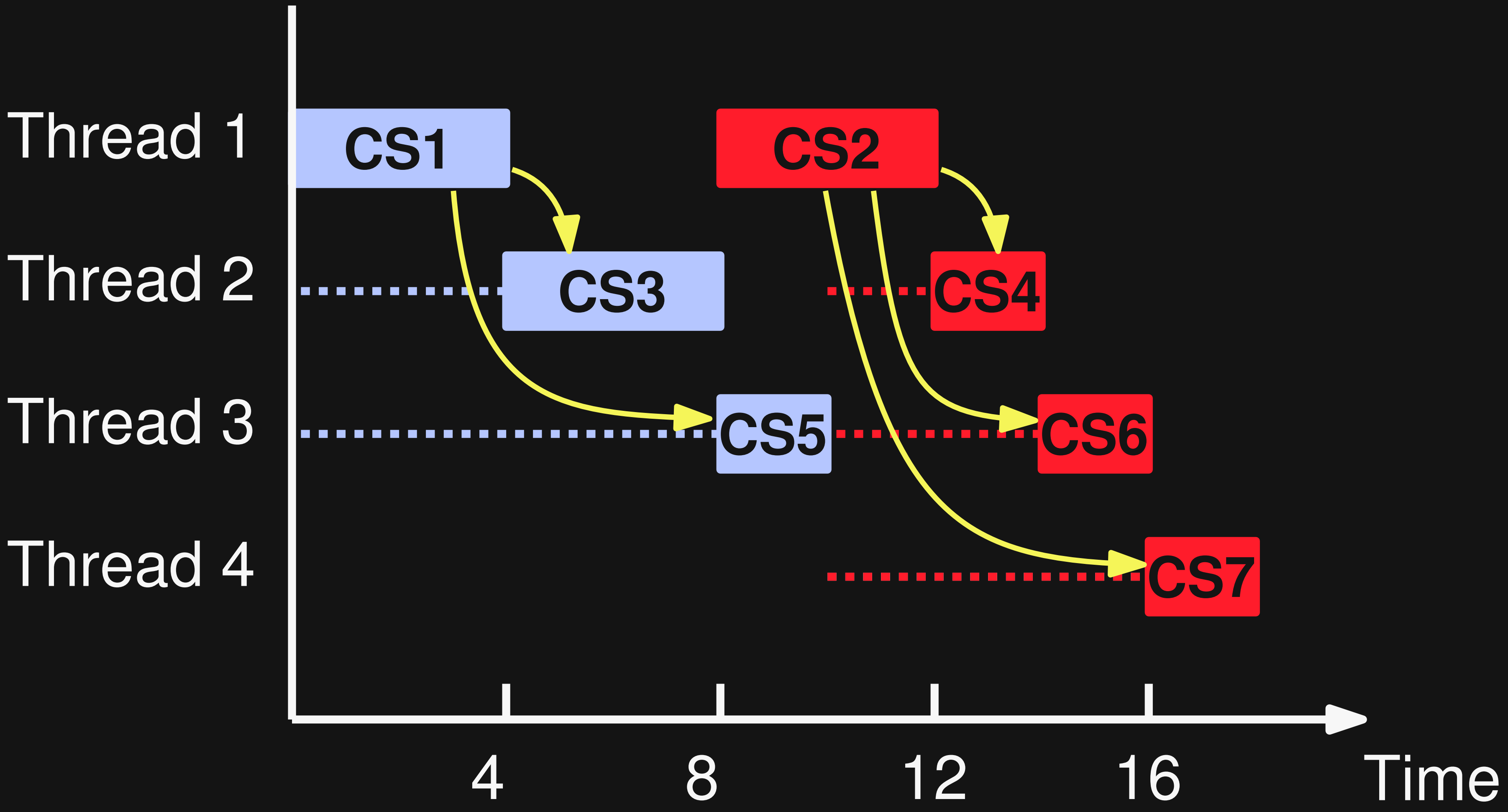
Example

Direct waits-for relations →



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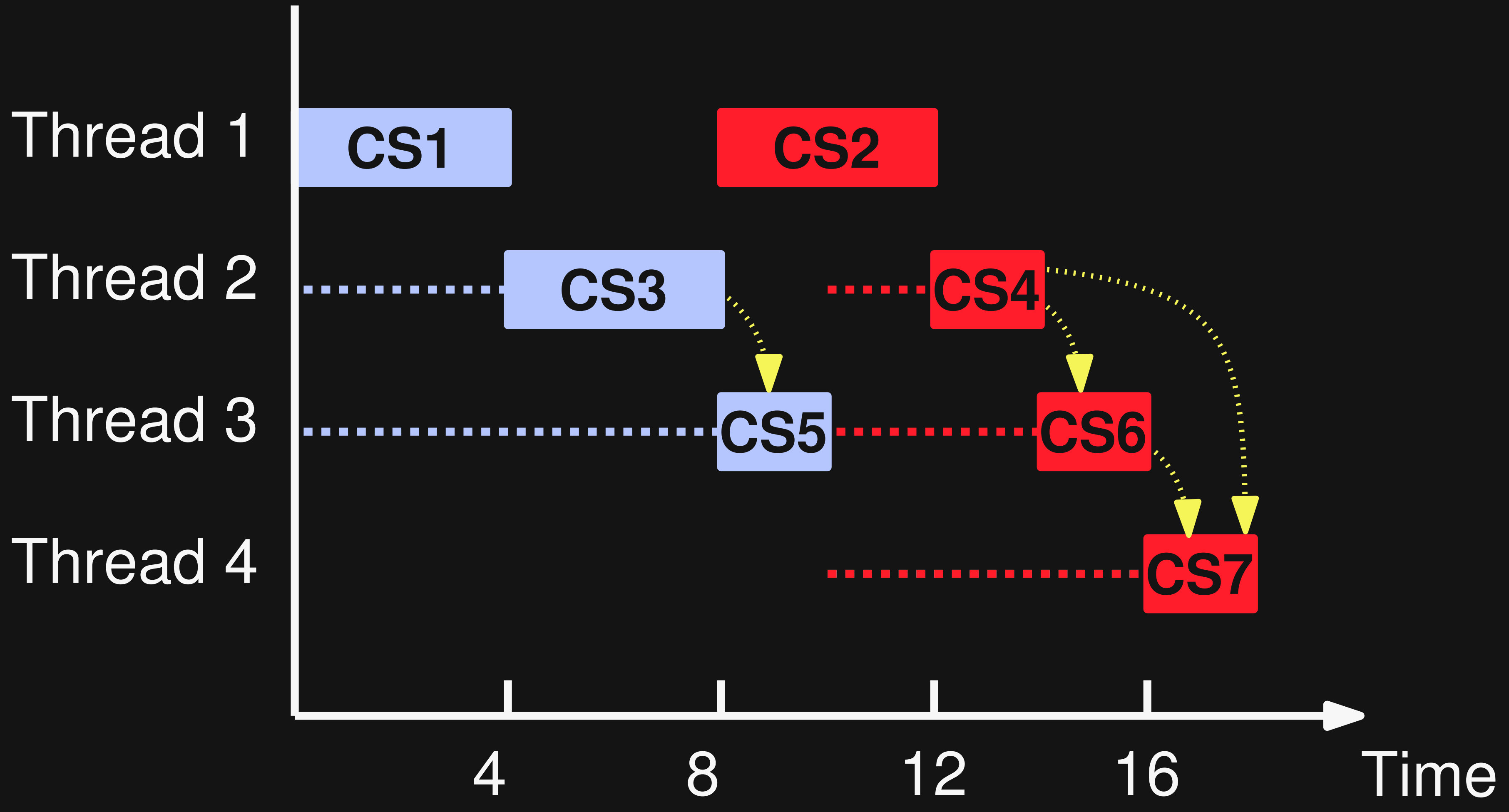
Example

Indirect waits-for relations ⇢



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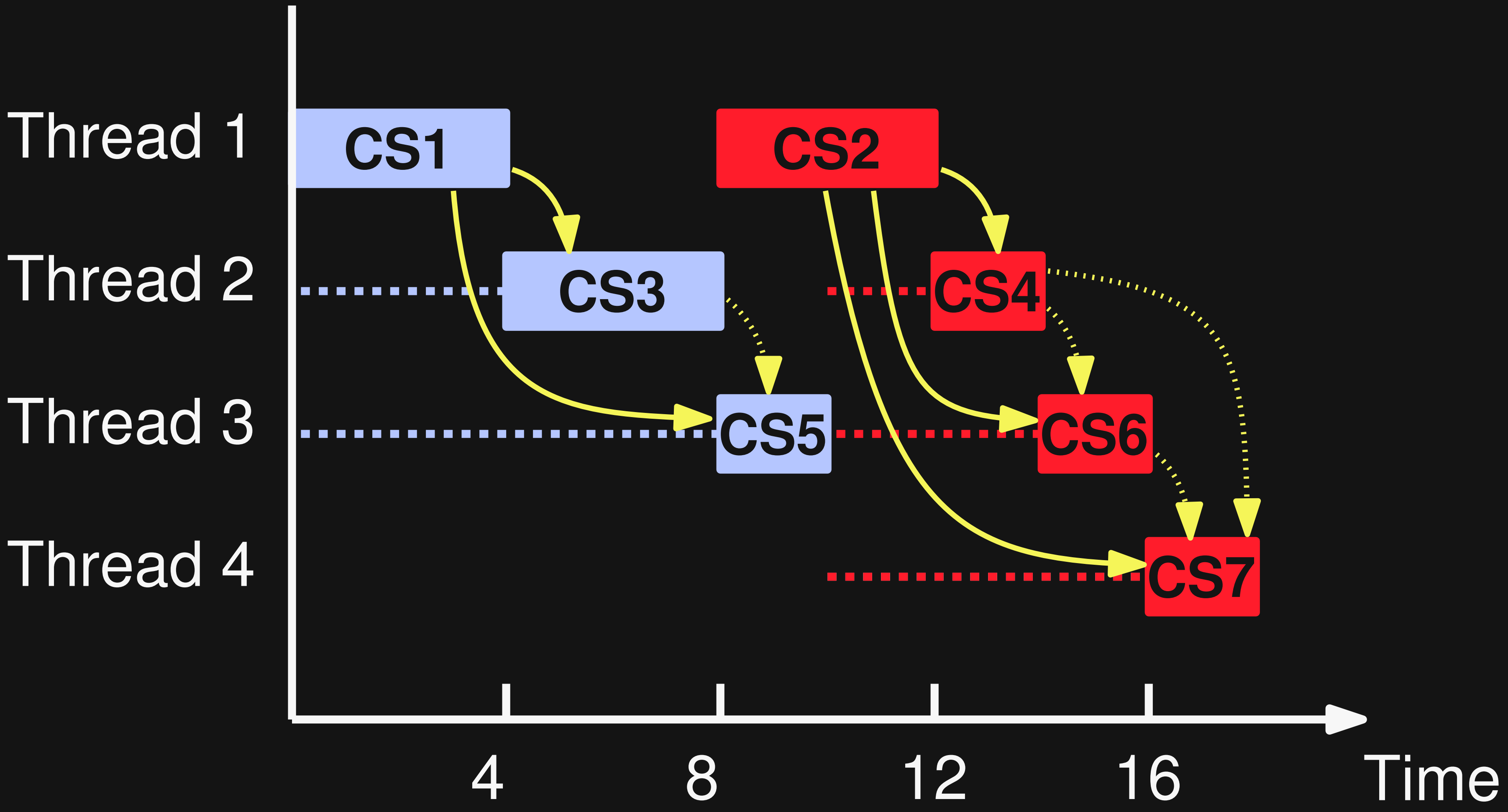
Example

Associate cost to each edge



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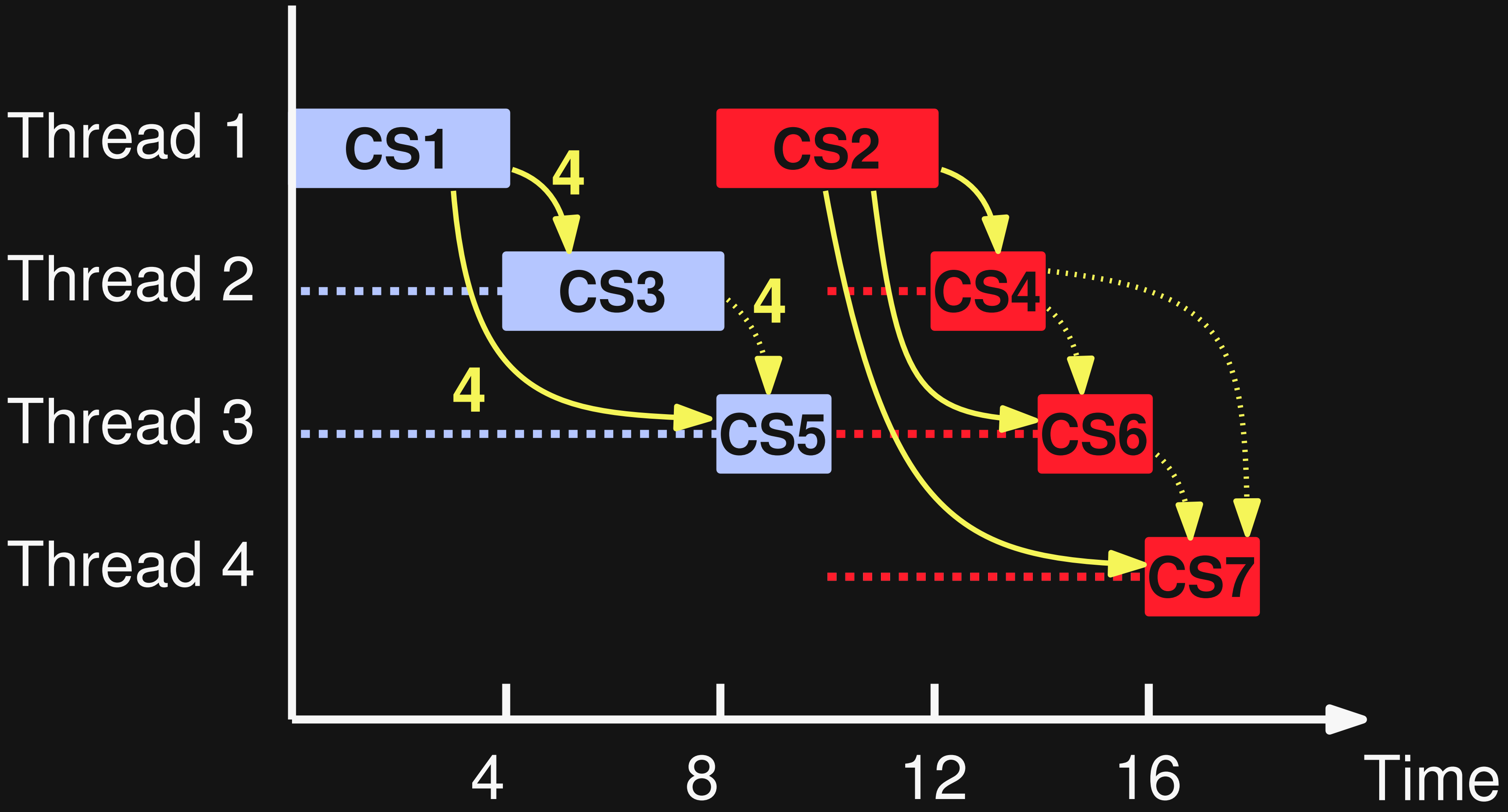

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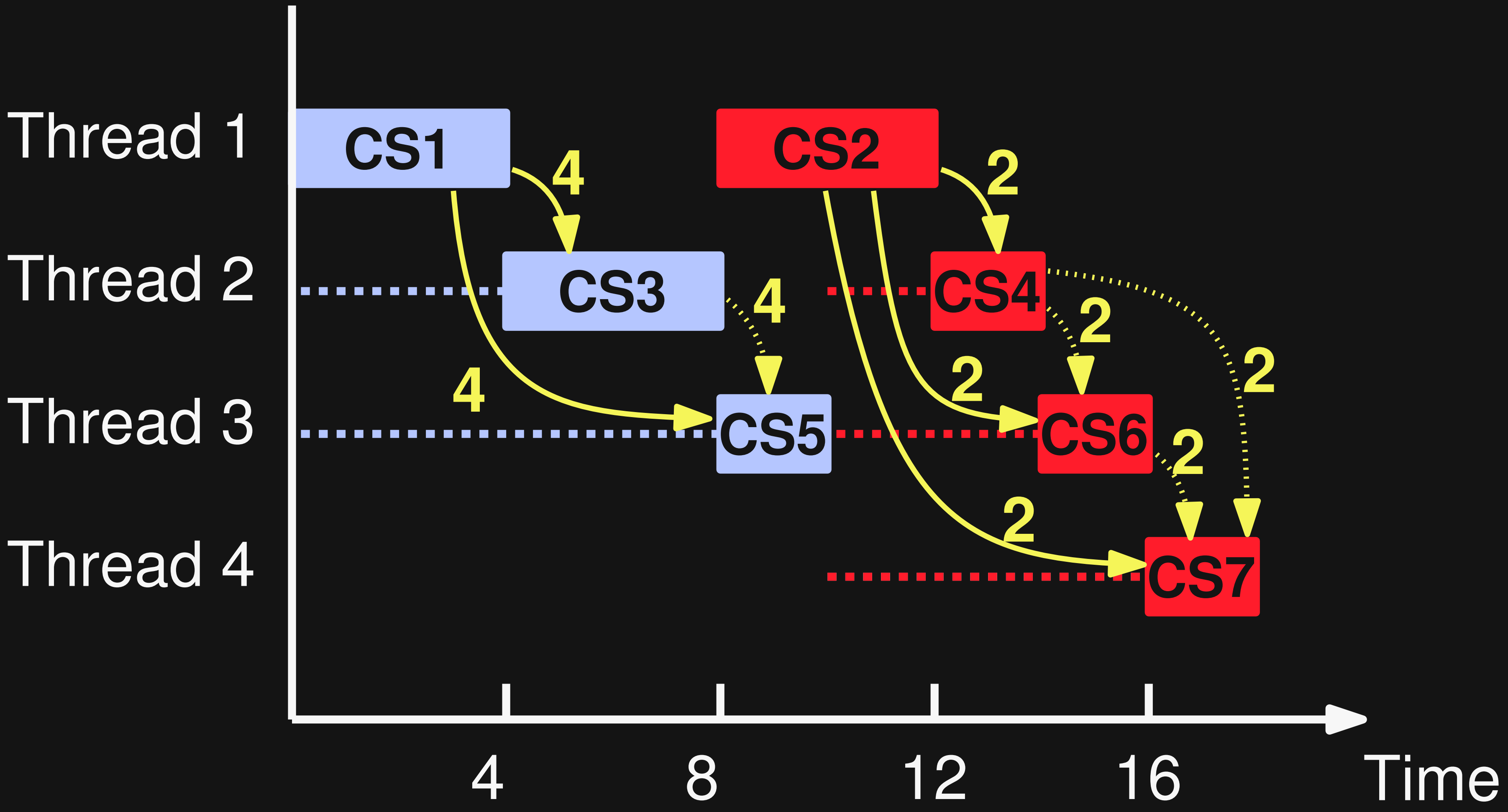

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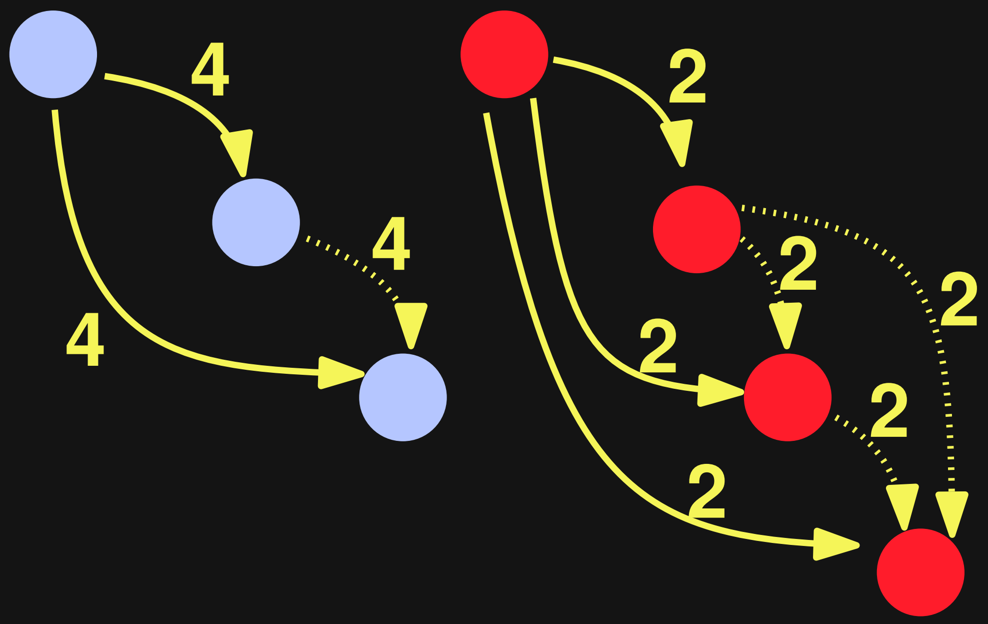
Example

Graph with cost-labeled edges



Measuring Performance Impact

Rank critical sections based on their likelihood to be the **root cause**

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Metric 1: All-path wait time

- How long did other critical sections wait for a particular critical section?

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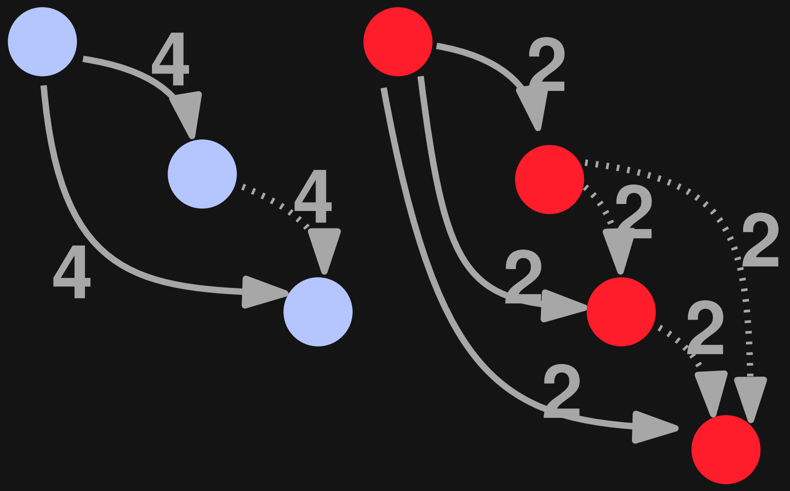

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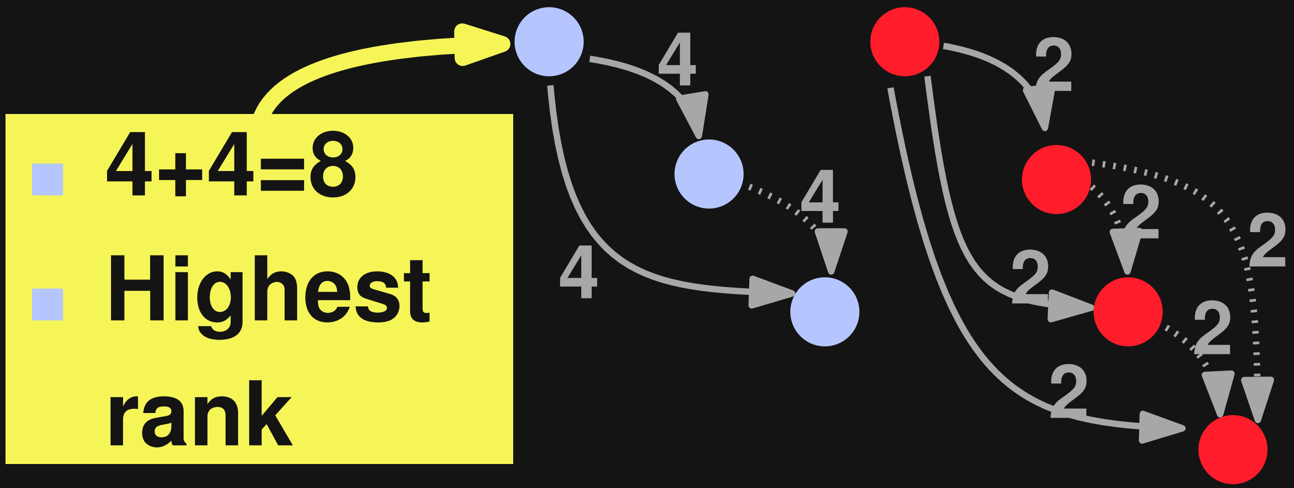

- 4+4=8
- Highest rank

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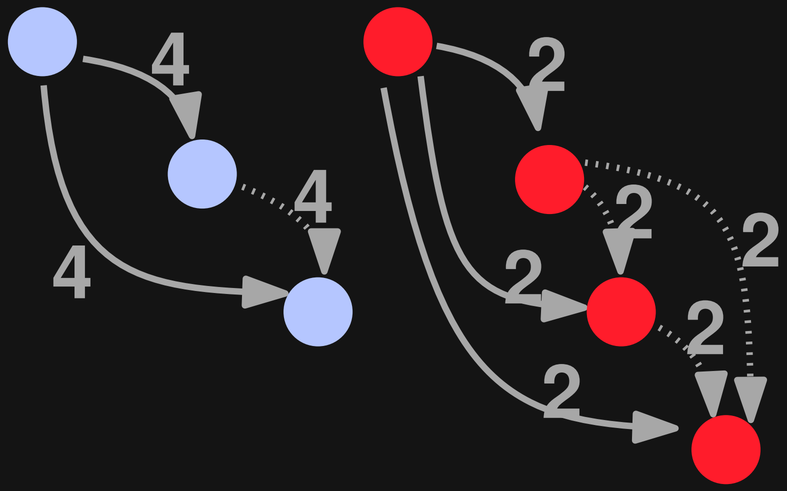

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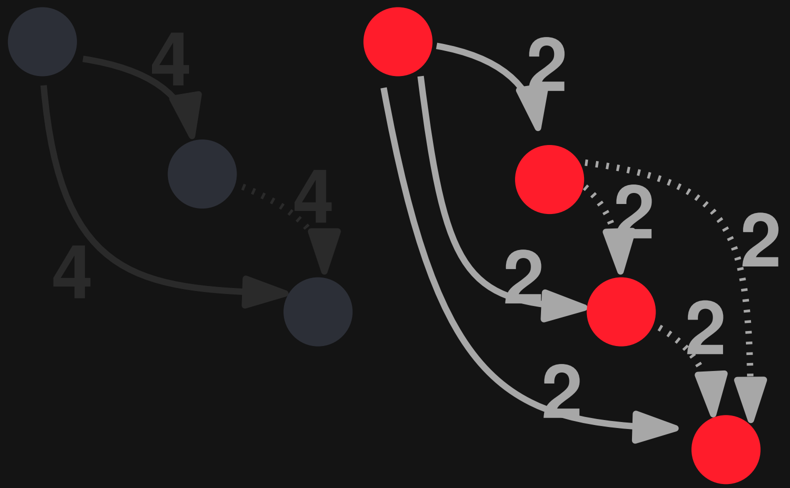

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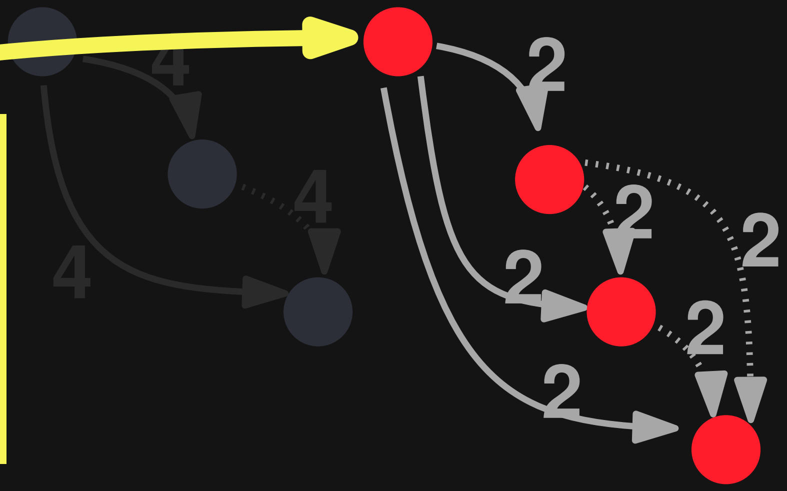

- 2+2+2=6
- Highest rank

Measuring Performance Impact

Rank critical sections based on their likelihood to be the root cause

Metric 3: All-path lock time

- How long did critical sections wait for a particular lock?

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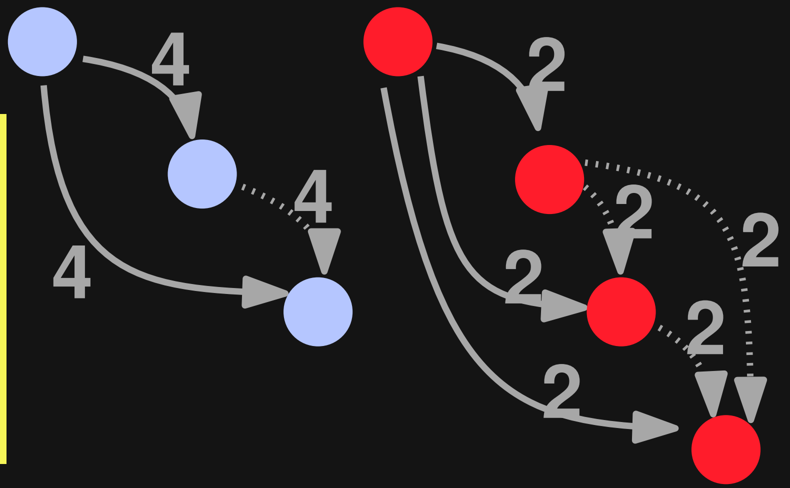
Rank critical sections based on their likelihood to be the **root cause**

Metric 3: **All-path lock time**

- How long did critical sections wait for a particular lock?

- 12 vs. 12
- Same rank



Measuring Performance Impact

Rank critical sections based on their likelihood to be the root cause

- One graph, several metrics
- Rank critical sections by one or more metrics

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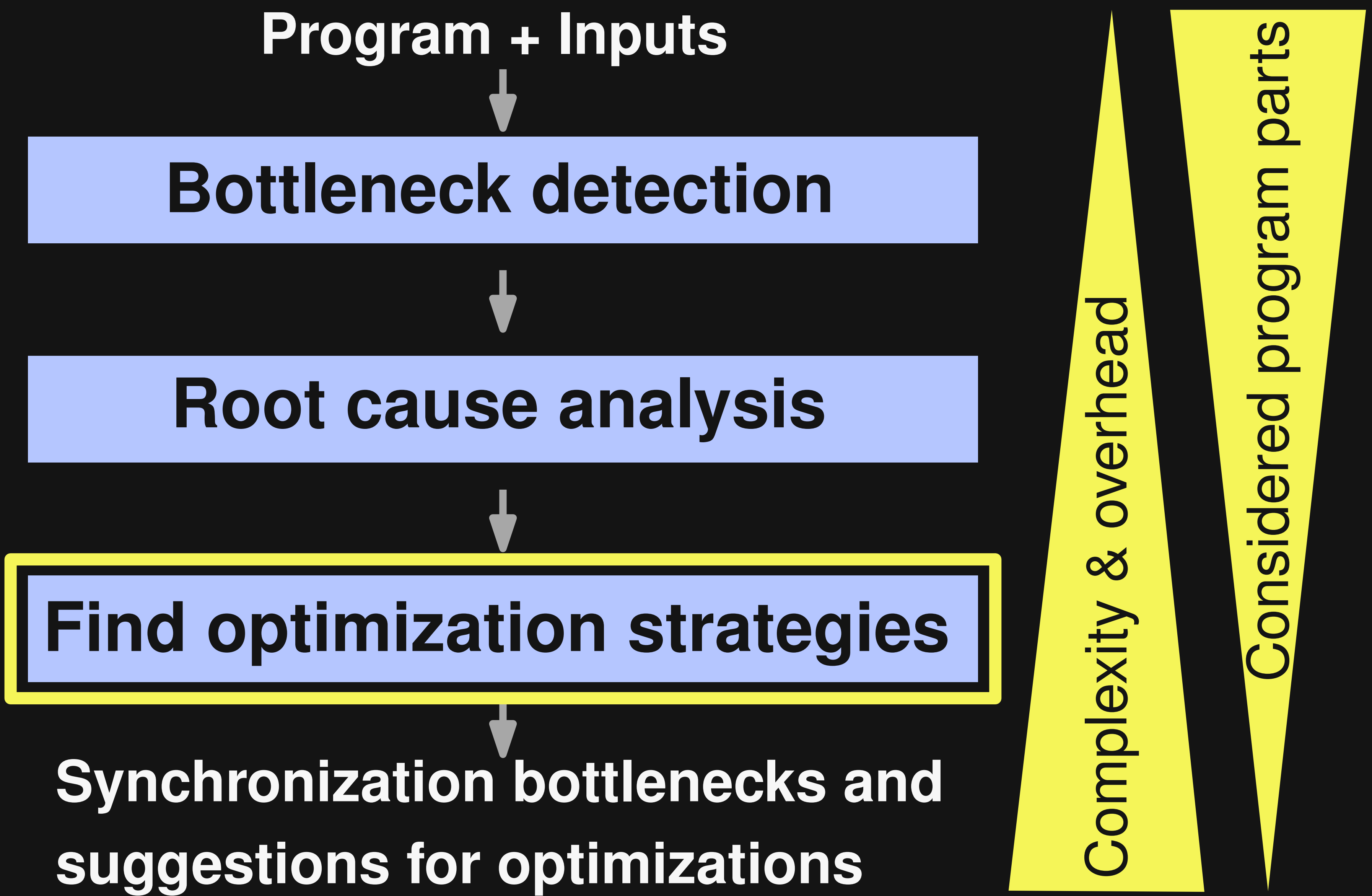

Program + Inputs

Bottleneck detection

Root cause analysis

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Complexity & overhead

Considered program parts

How to Optimize the Bottlenecks?

Challenge: Bottleneck $\not\Rightarrow$ Optimizable

Dynamic analysis of likely root causes:

- Track reads and writes of critical sections
- Merge information across executions
- Suggest common optimization patterns

Pattern-based Suggestions

Suggest to ..	When ..
eliminate synchronization	no shared memory access
split lock	critical sections access disjoint memory
use read-writer lock	mostly read-only critical sections

Evaluation: Setup

Questions

- Effectiveness
- Efficiency
- Comparison with Valgrind’s lock contention profiler

Setup

- Firefox, MySQL, 6 benchmarks
- 15 known bottlenecks

Detected Bottlenecks

18 bottlenecks (15 known + 3 new)

Rank root cause by critical section

- 8 of 18 ranked first
- All in top 5% (of 27–119 critical sections)

Rank root cause by lock

- 15 of 18 ranked first

Optimizations

Out of 18 bottlenecks:

- **9 optimizations suggested**
  - 7 match fix by developers
  - 2 false suggestions
- **5 reported as low-degree conflicts**
  - Application-specific optimizations needed
- **4 without any match**

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Example: MySQL

- **Remove unnecessary lock for read-read accesses**

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Example: Splash-2 Radiosity

- **Turn shared queue into non-blocking queue**

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Example: MySQL

- **Instead of shared output buffer, use two buffers**

Comparison with Valgrind

	Valgrind	SyncProf
Inputs & executions	Developer must choose	Automatically selected and summarized
Critical sections to inspect	Rank 1 to 14	Rank 1 to 5
	Reduced by 55% (avg.)	
Optimizations	No support	Common patterns

Efficiency

Runtime overhead

- Root cause analysis: 4x–10x
- Optimization suggestion: 60x–100x

Total time: 13–340 minutes per program

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Acceptable for in-house profiling

Conclusion

SyncProf: Actionable performance profiling for concurrent programs

- Detect bottlenecks
- Identify root causes
- Suggest optimizations

Take-aways for analysis writers

- Multi-stage analysis with increasing complexity
- Generic graph as basis for multiple analyses

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Thanks!