An Automated, Cross-Layer Instrumentation Framework for Diagnosing Performance Problems in Distributed Applications

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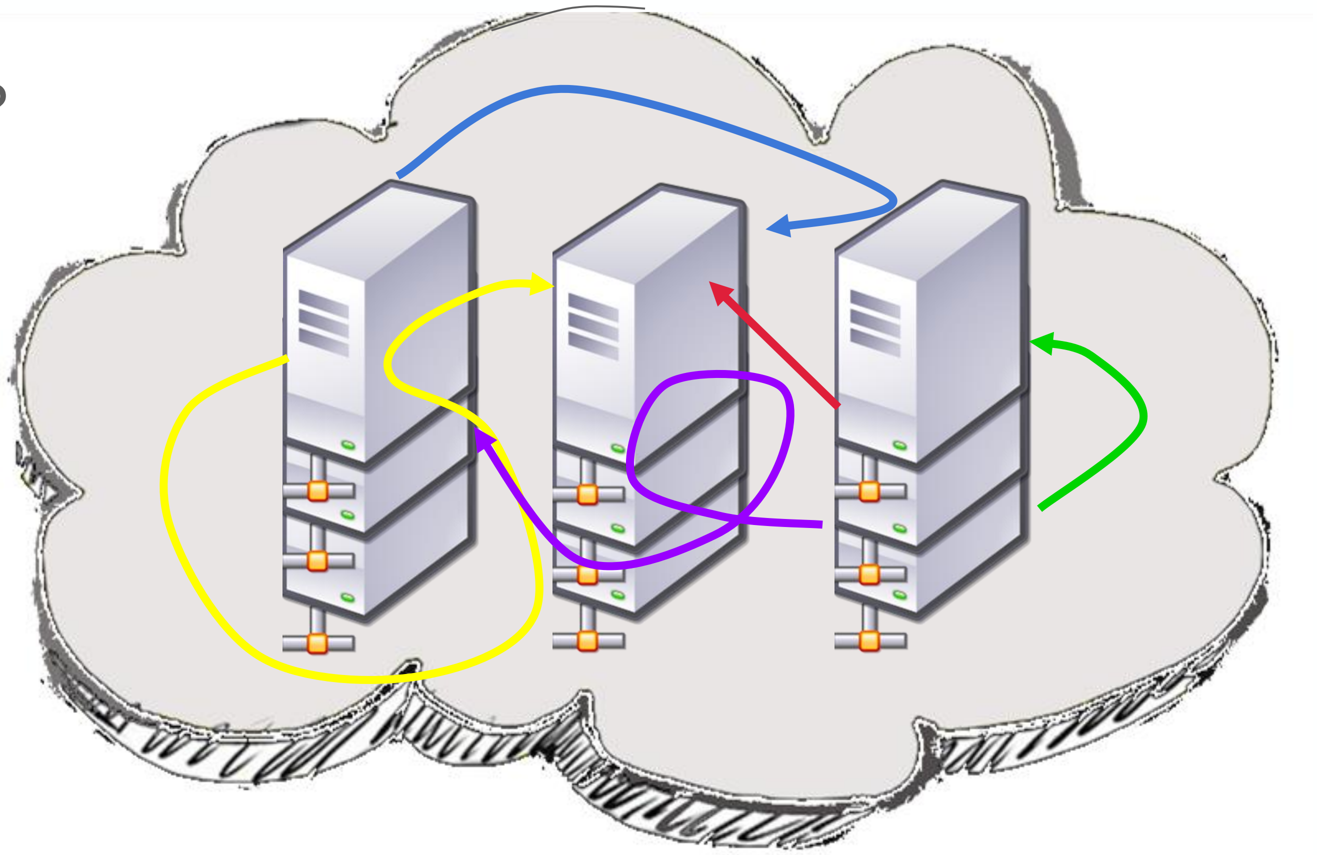
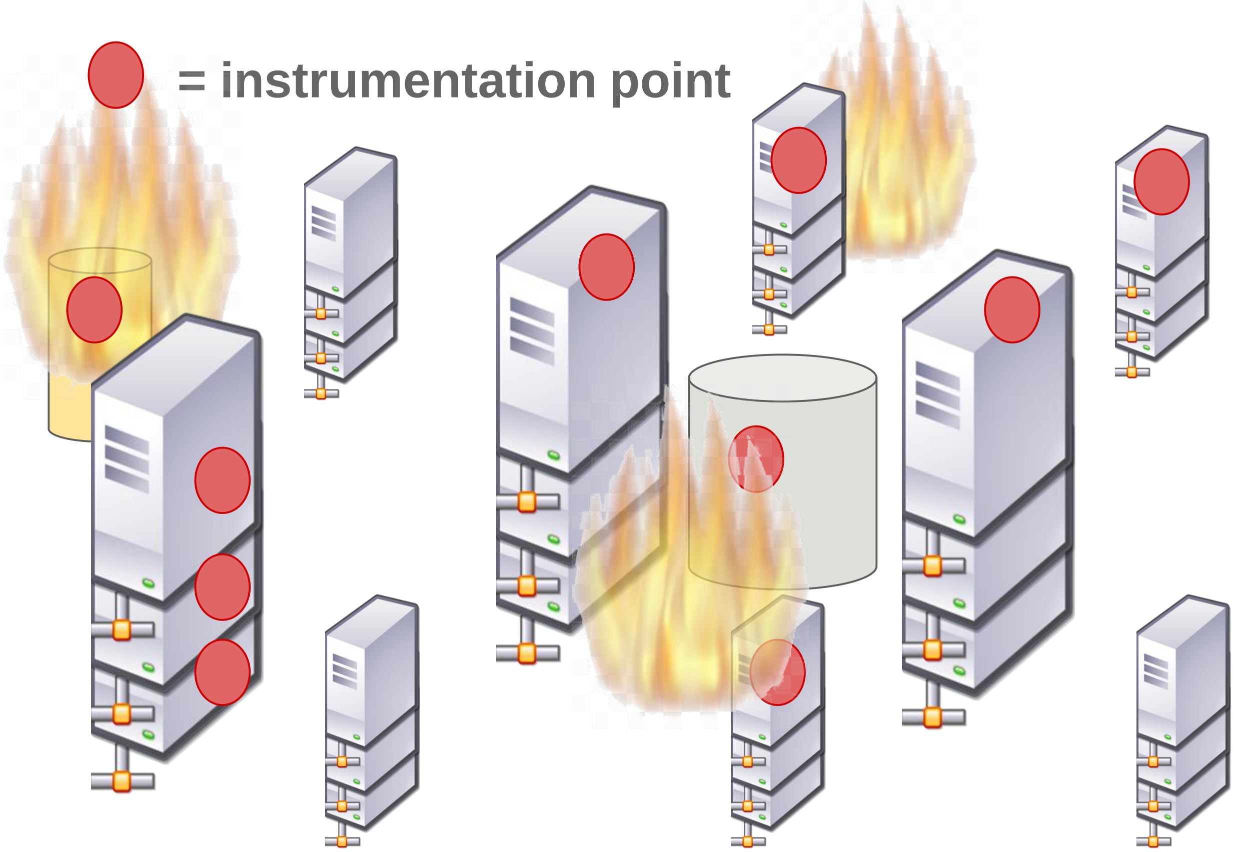
Debugging Distributed Systems

Challenging: Where is the problem?
It could be in:

- One of many components
- One of several stack levels
  - VM vs. hypervisor
  - Application vs. kernel
- Inter-component interactions



Today’s Debugging Methods

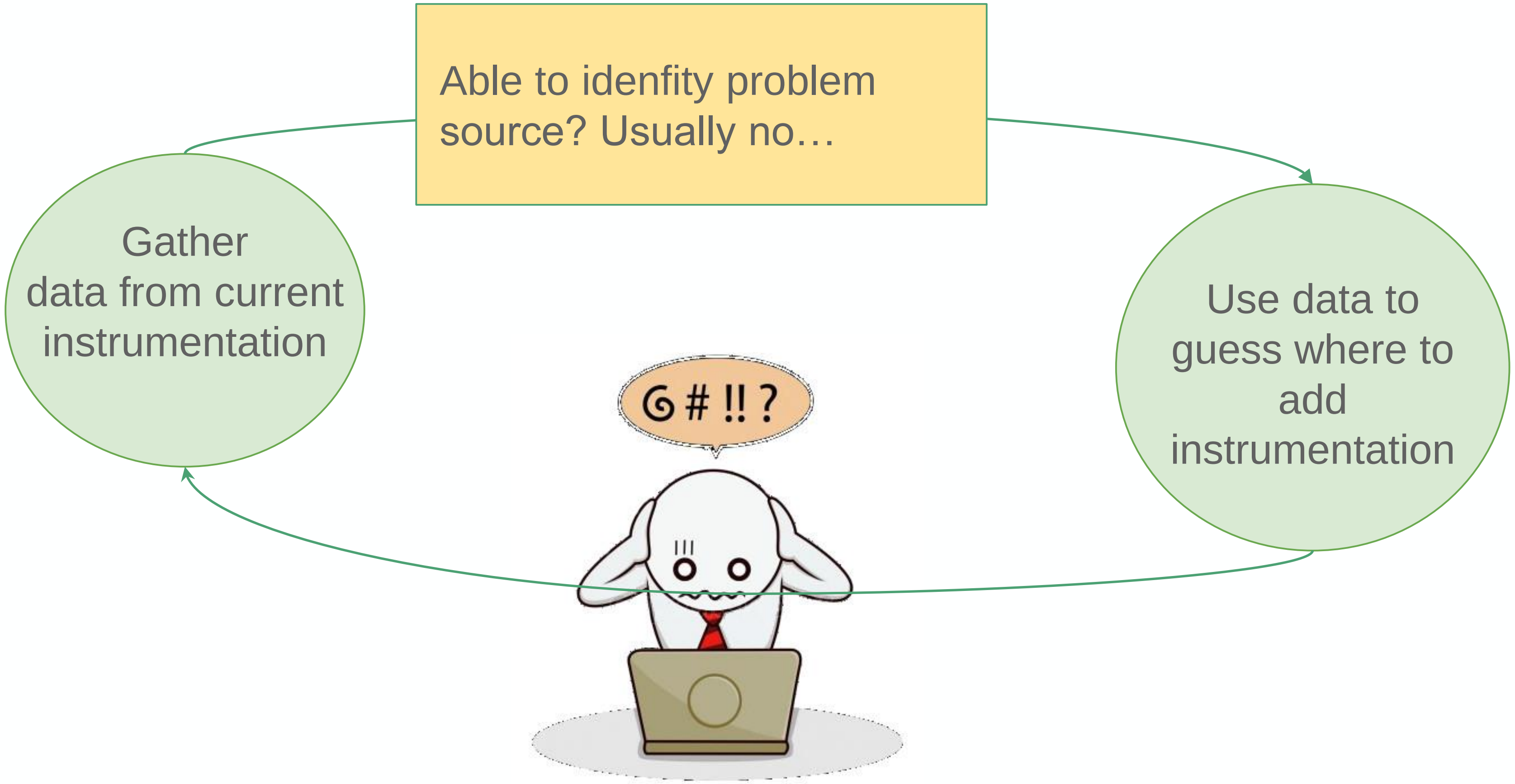


Instrumentation data

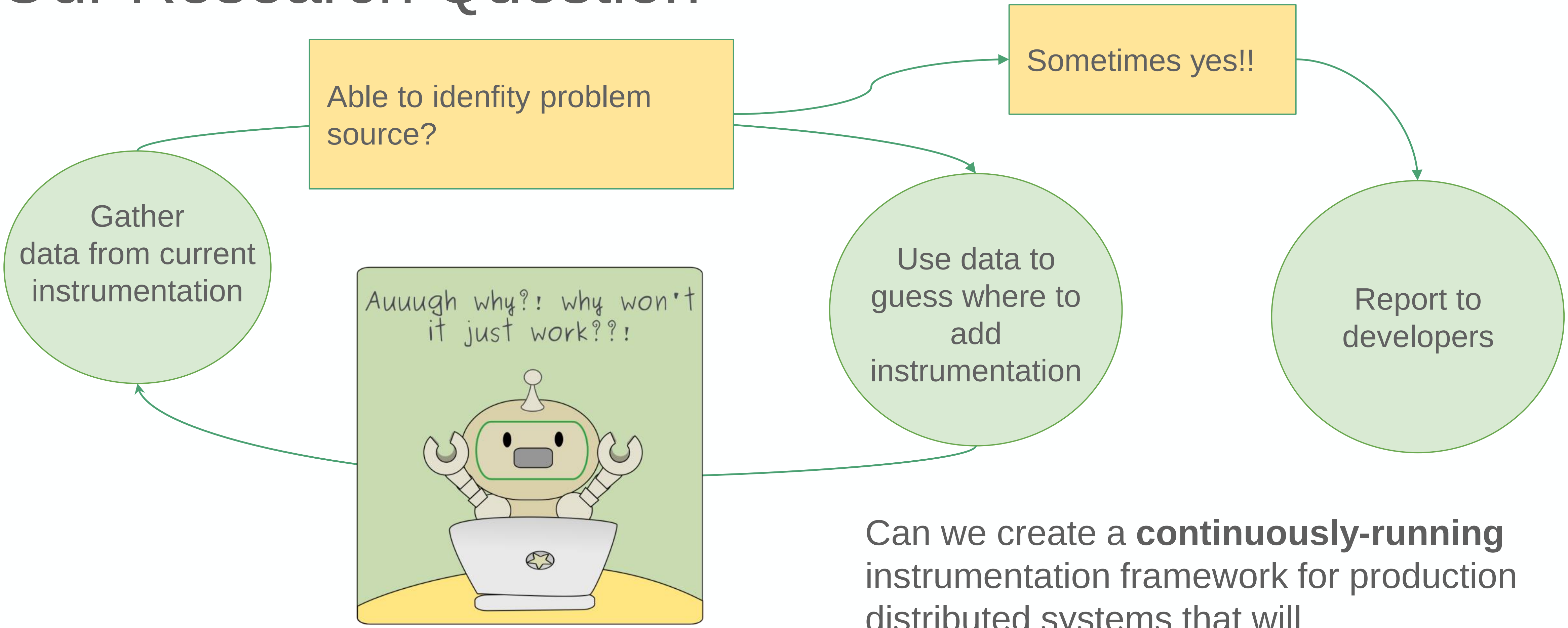
Different problems benefit from **different** instrumentation points.

You can’t instrument everything: too much overhead, too much data.

Today’s Debugging Cycle



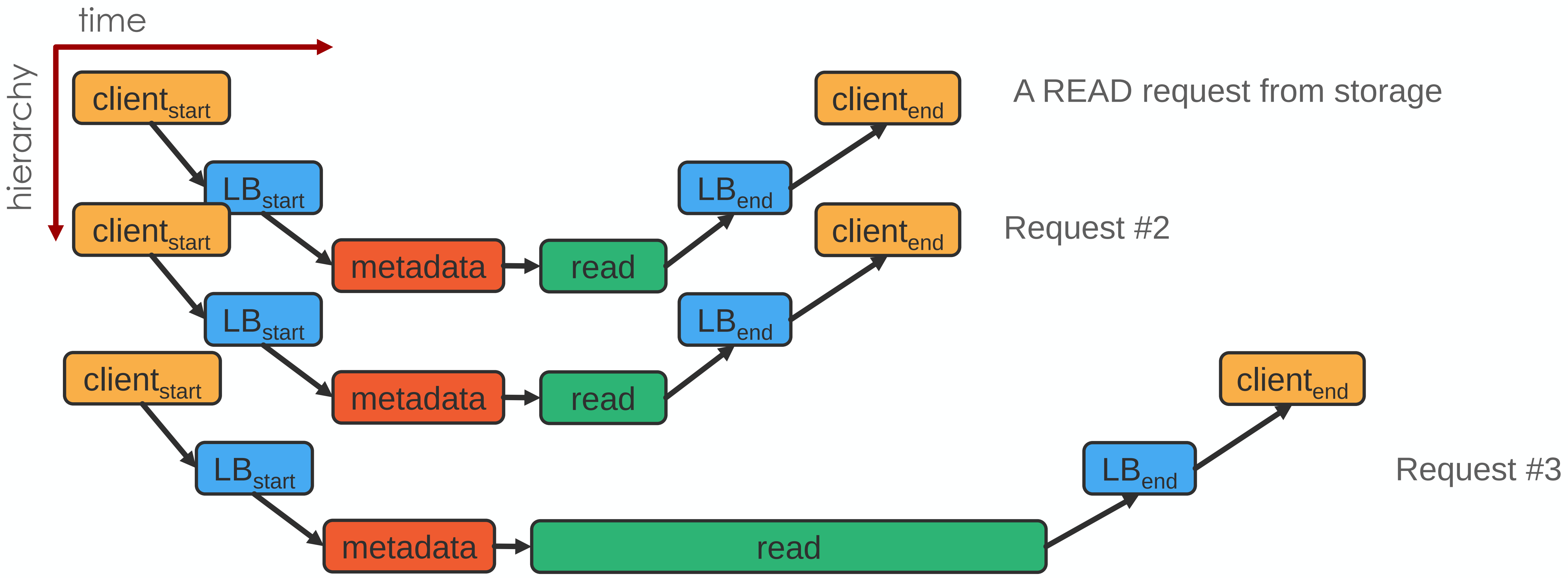
Our Research Question



Can we create a **continuously-running** instrumentation framework for production distributed systems that will **automatically explore instrumentation choices** across stack-layers for a newly-observed performance problem?

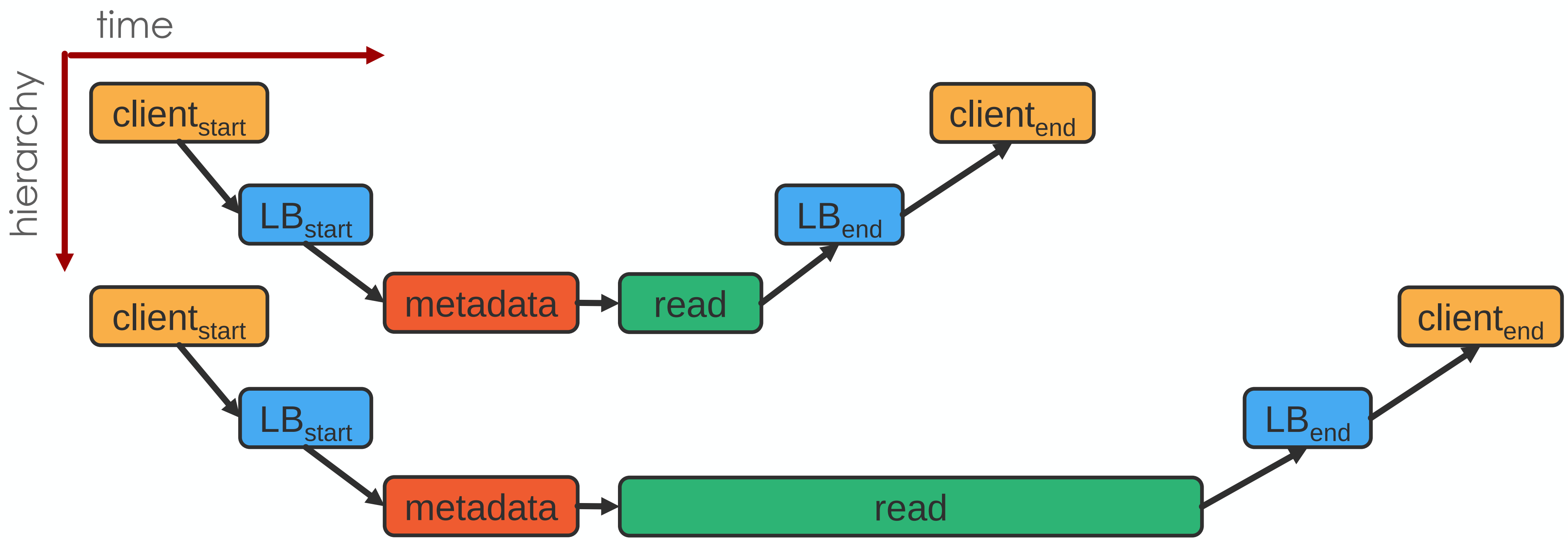
Key insight: Performance variation indicates where to instrument

- If requests that are expected to perform similarly do not:
  - There is something unknown about their workflows, which could represent performance problems
  - Localizing source of variation gives insight into where instrumentation is needed.

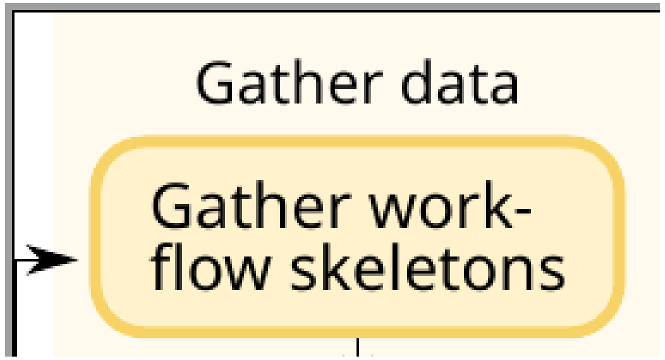


Key Enabler: Workflow-centric Tracing

- Used to get workflows from running systems
- Works by propagating common context with requests (e.g., request ID)
  - Trace points record important events with context
- Granularity is determined by instrumentation in the system



Vision of Pythia



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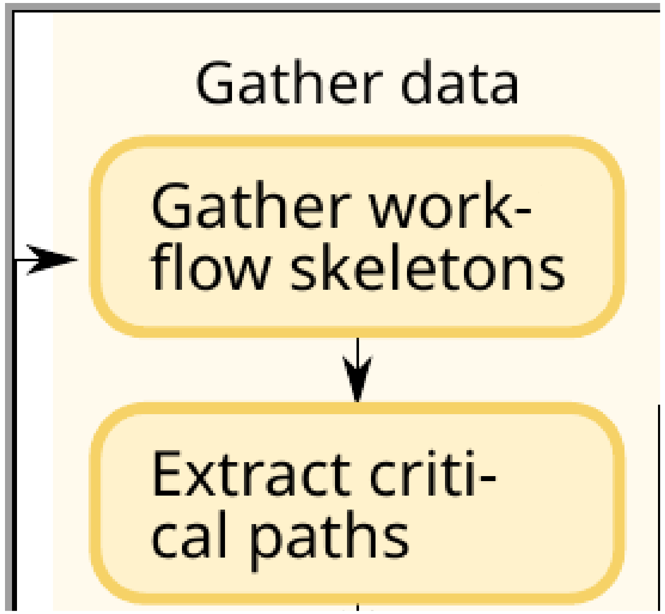

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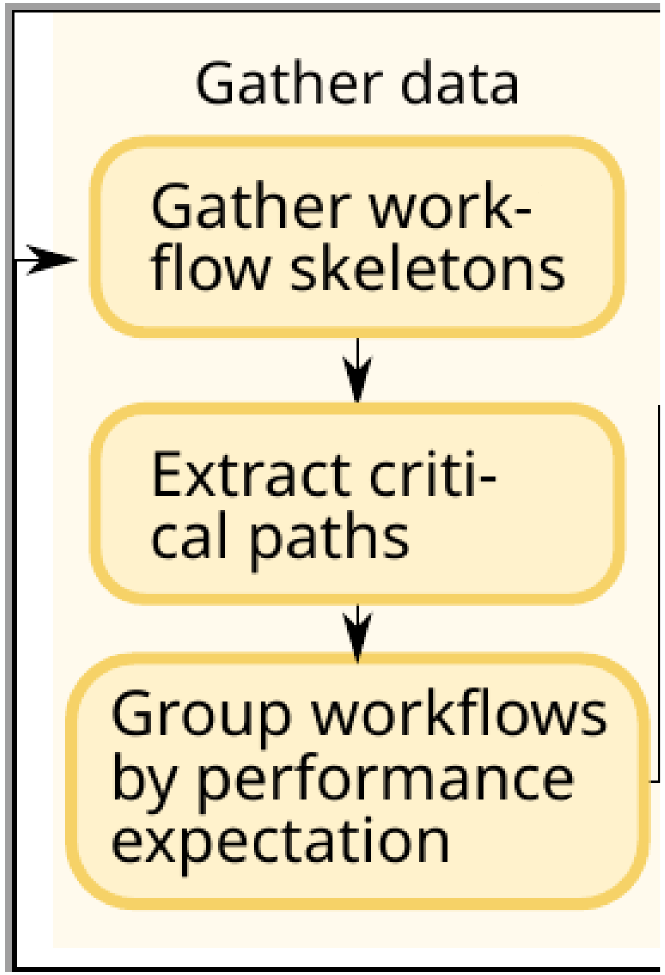

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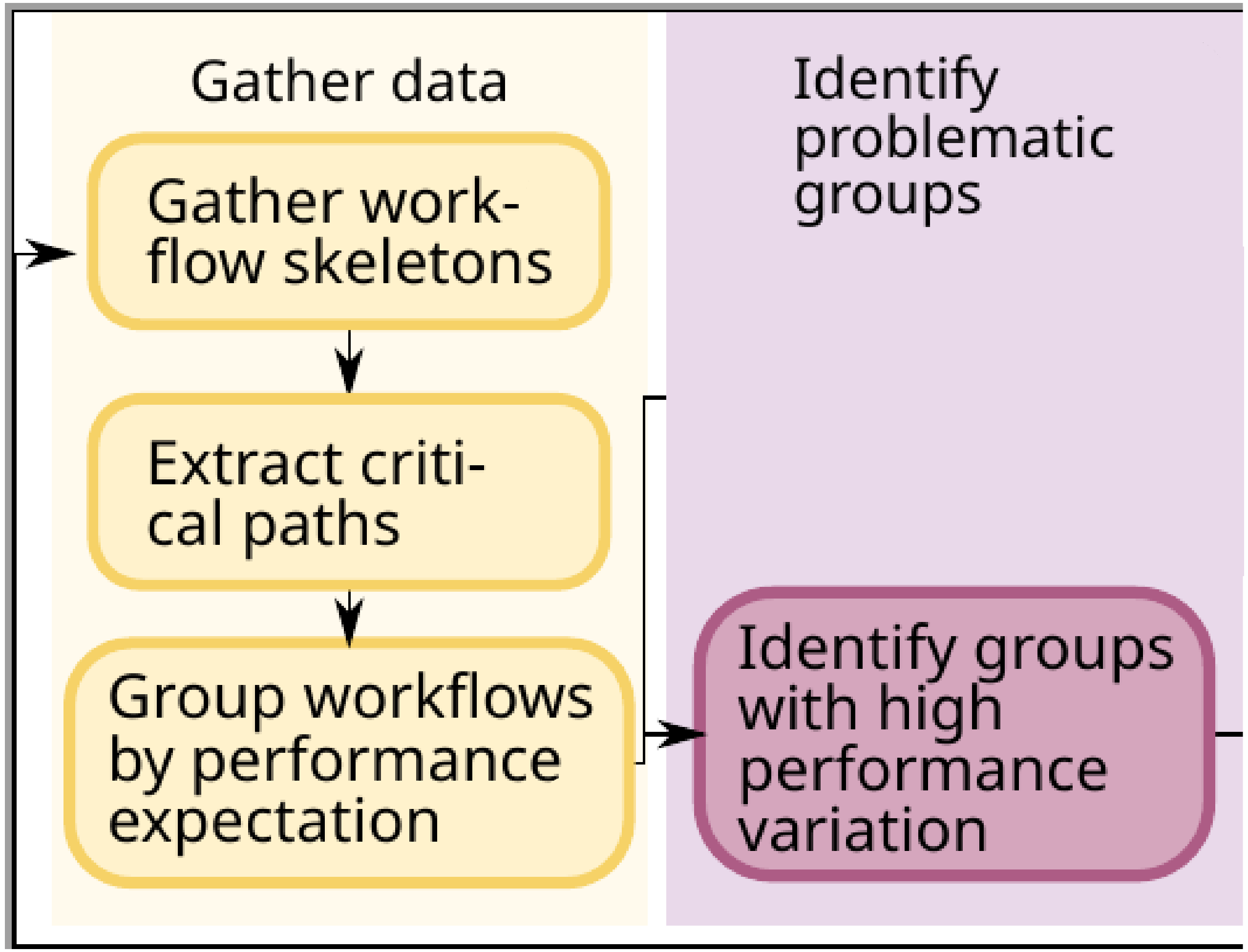

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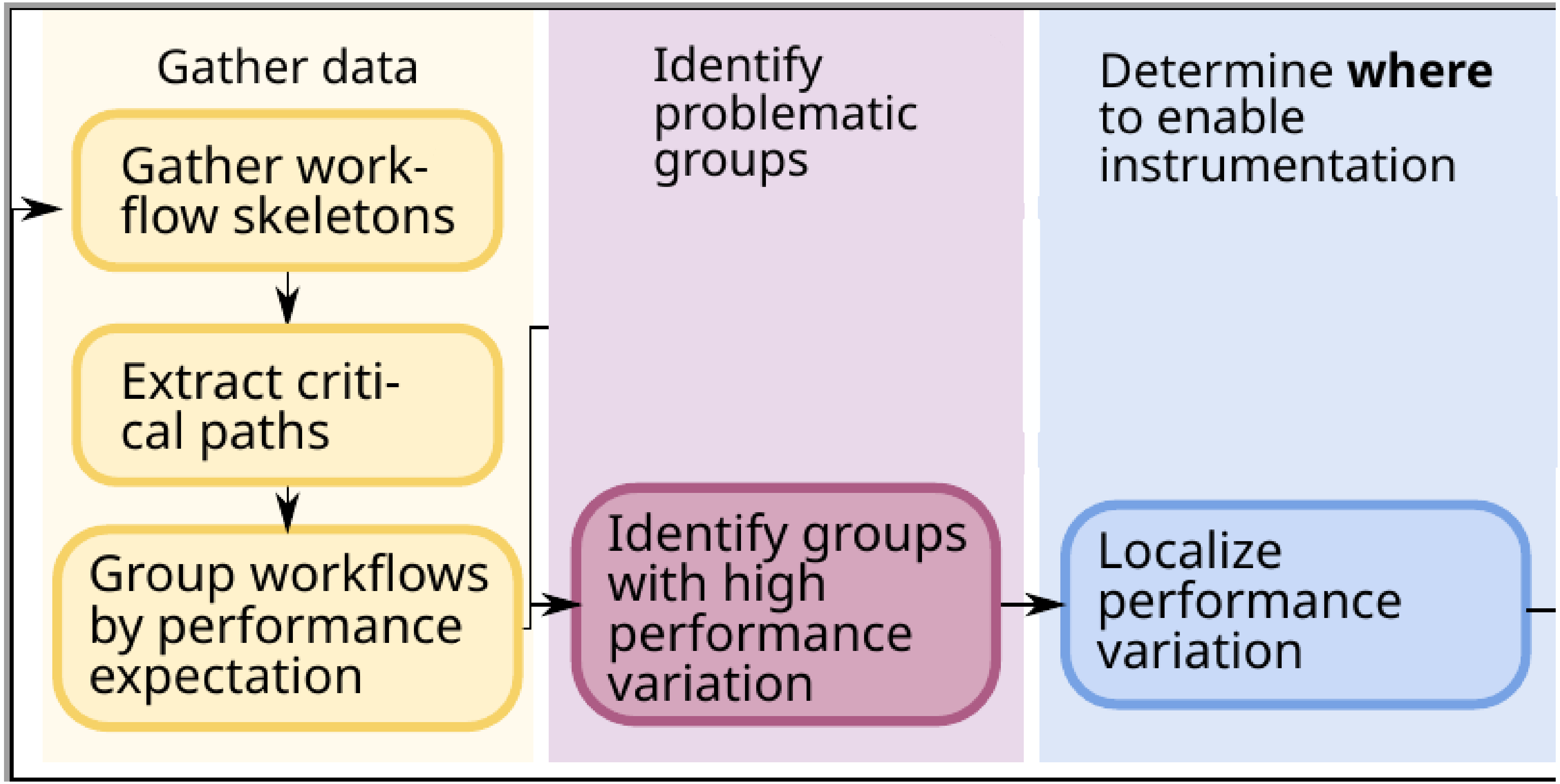

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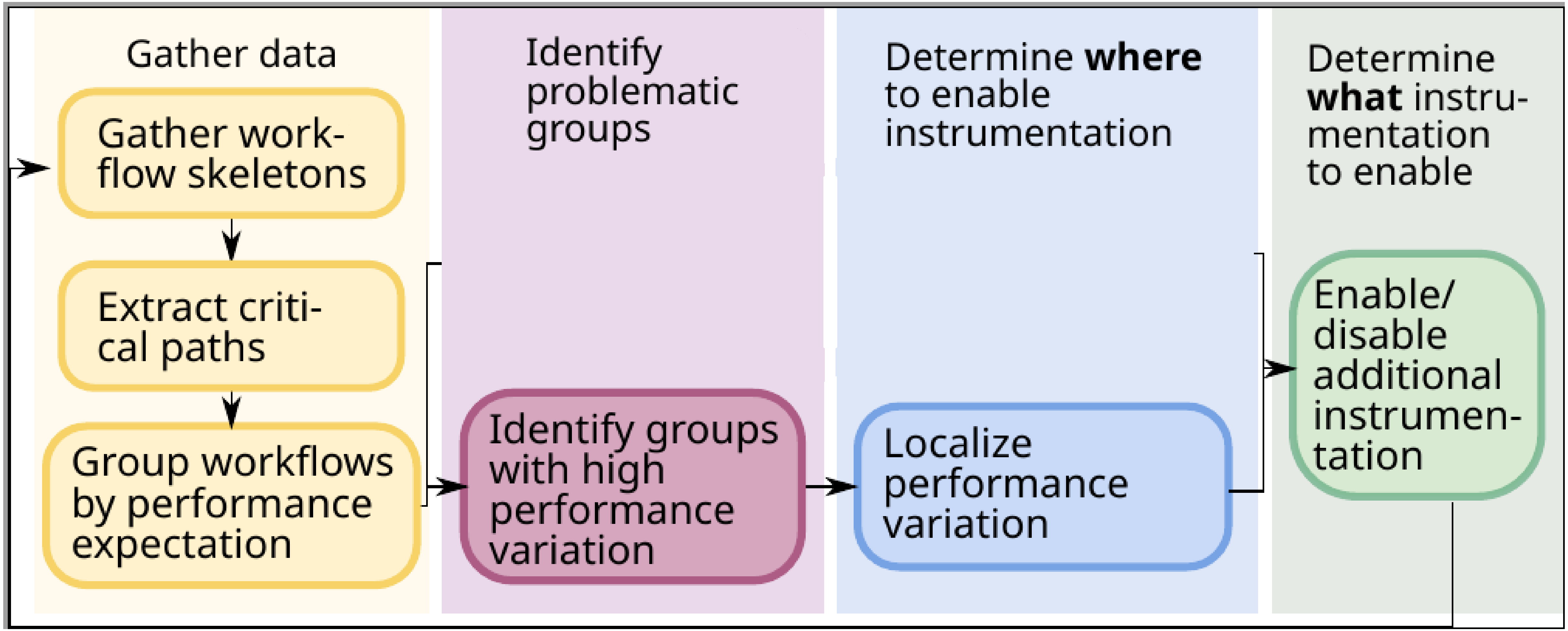

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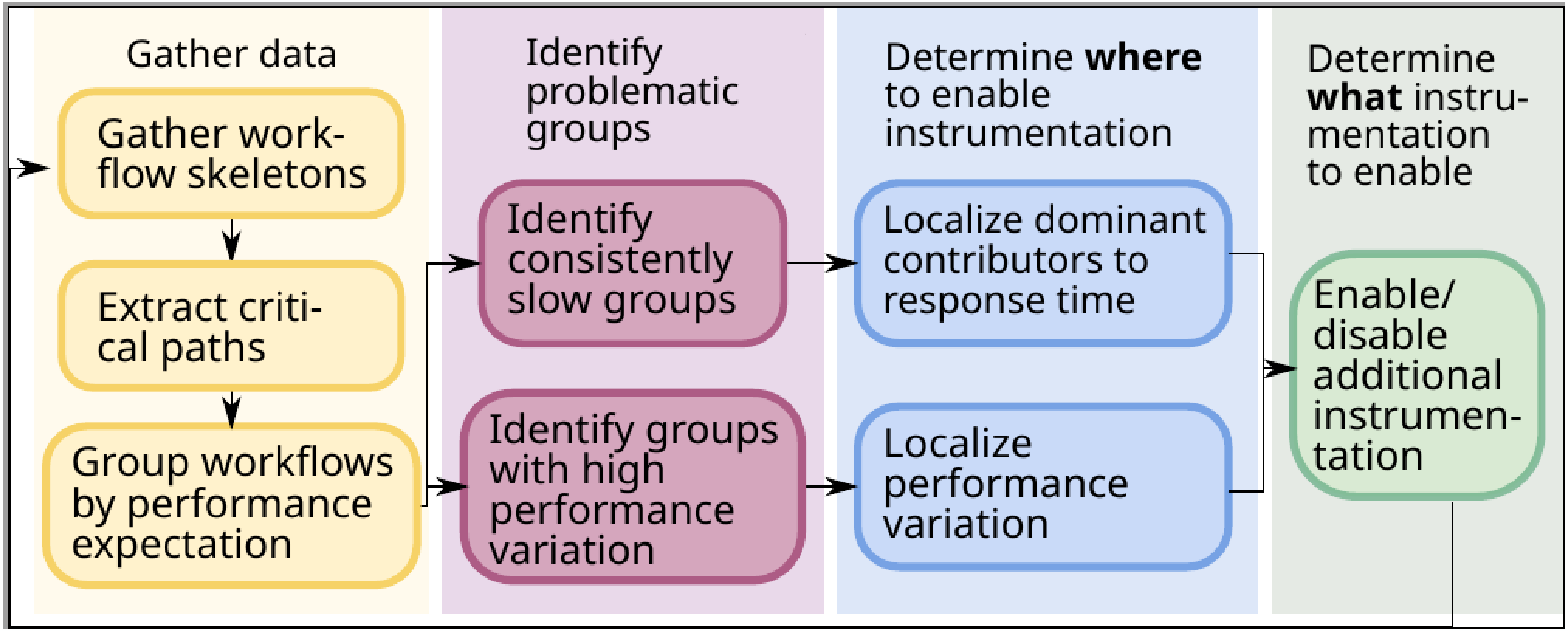

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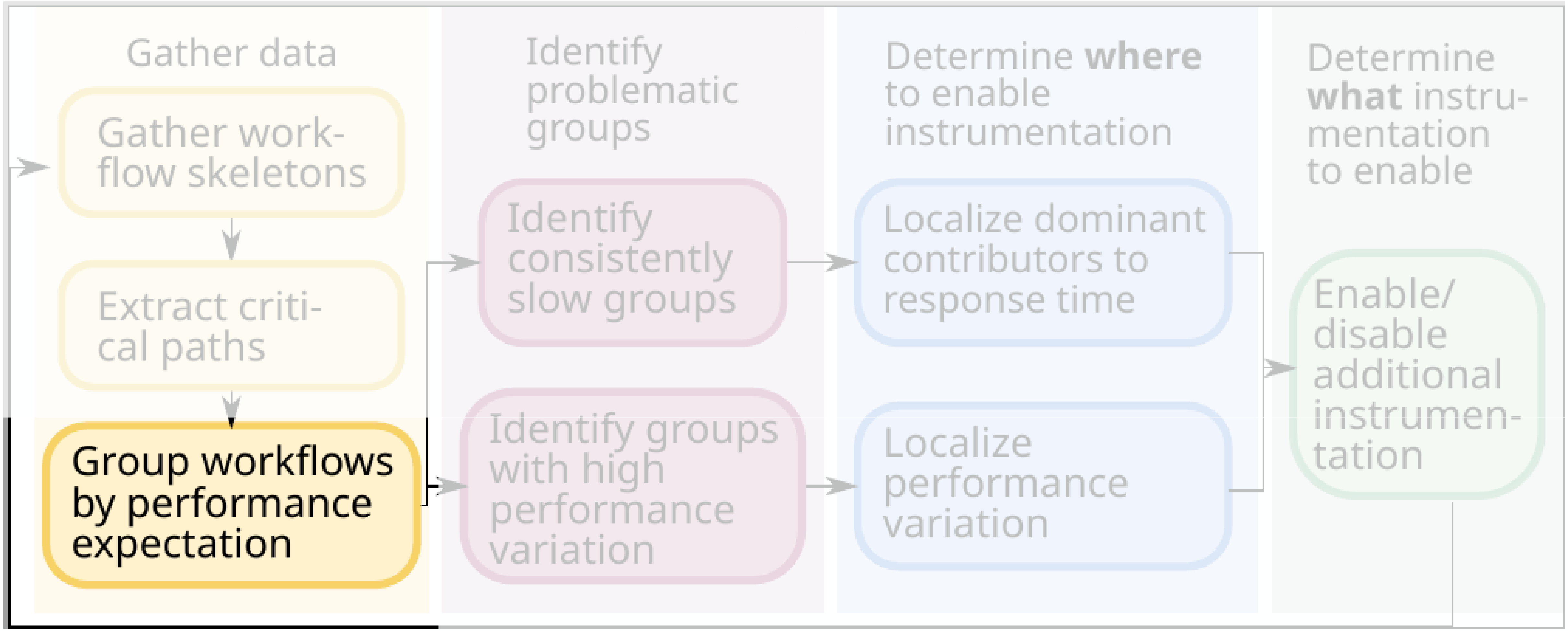

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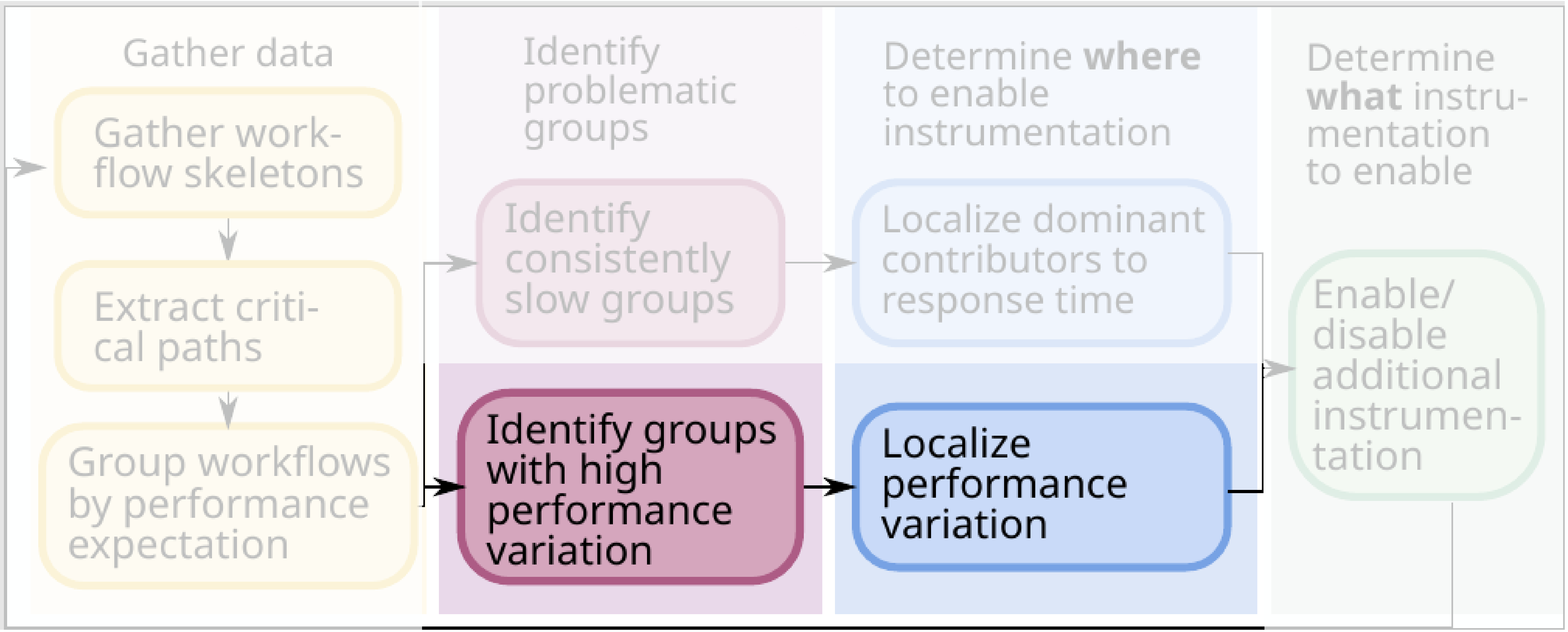

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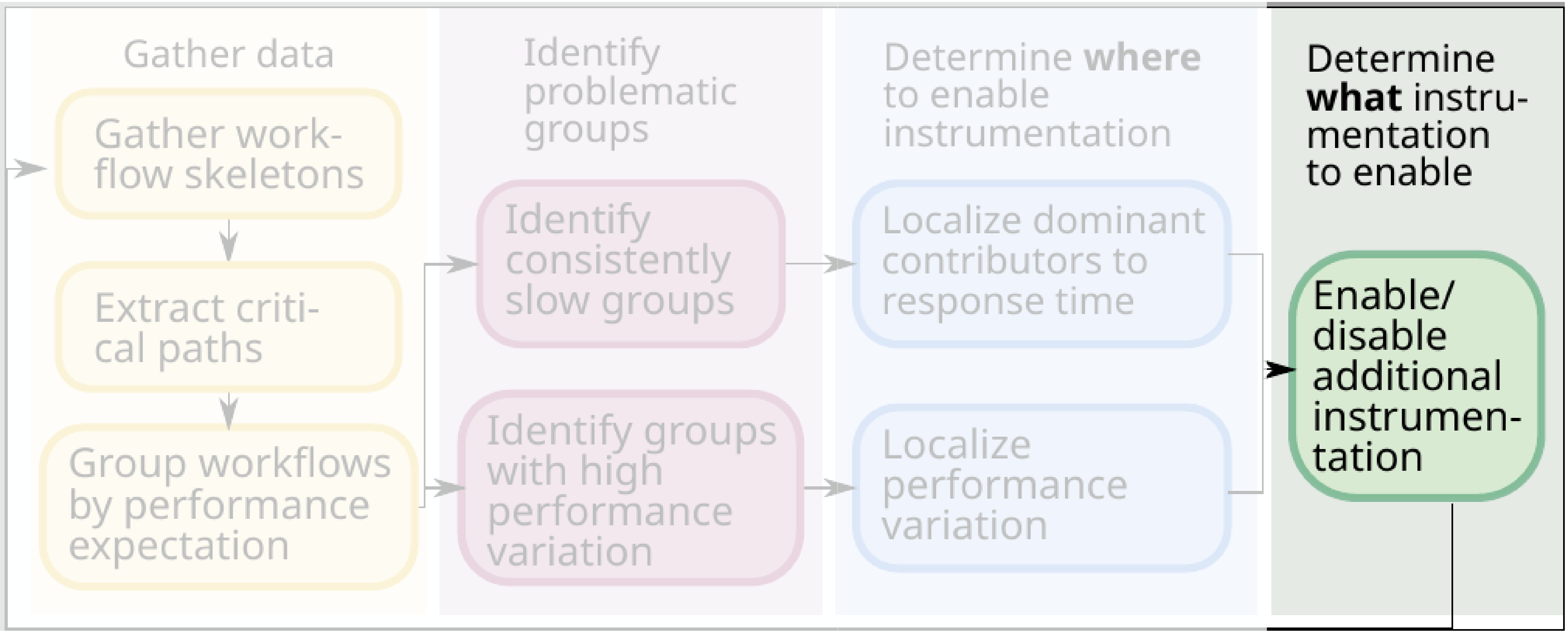
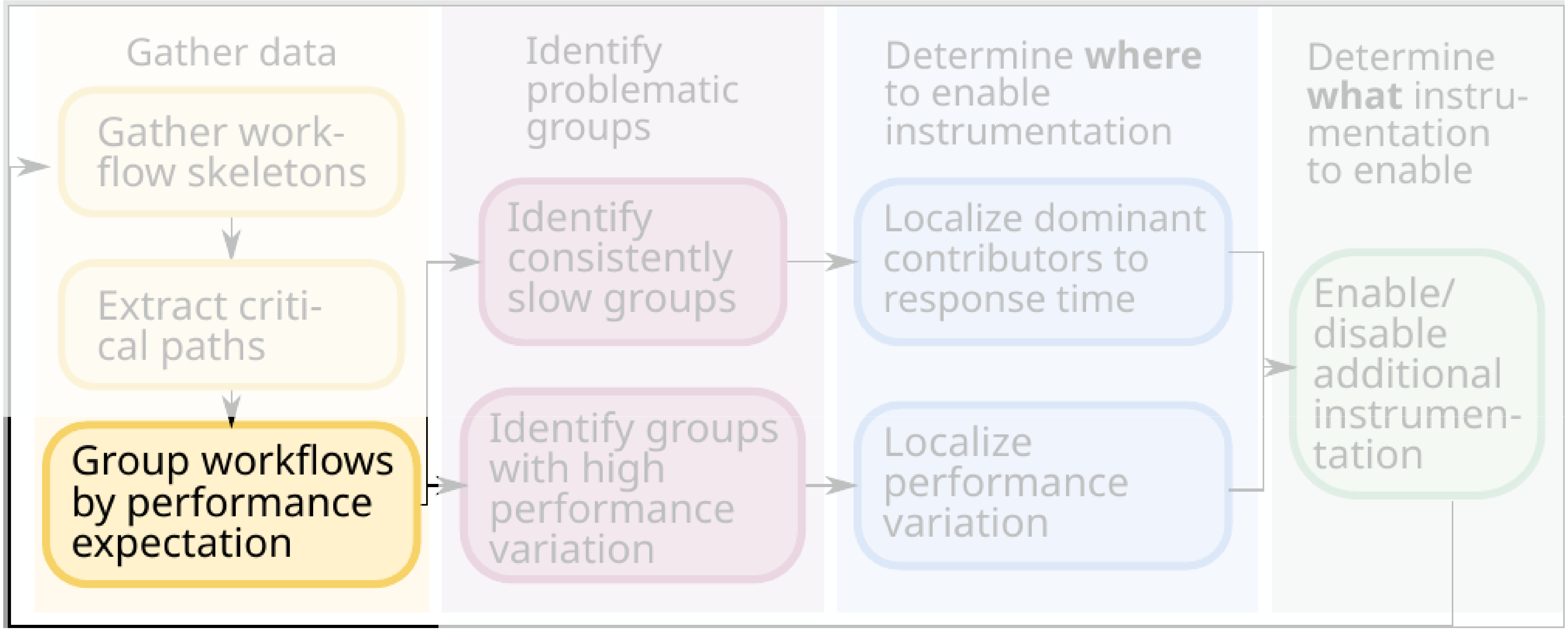
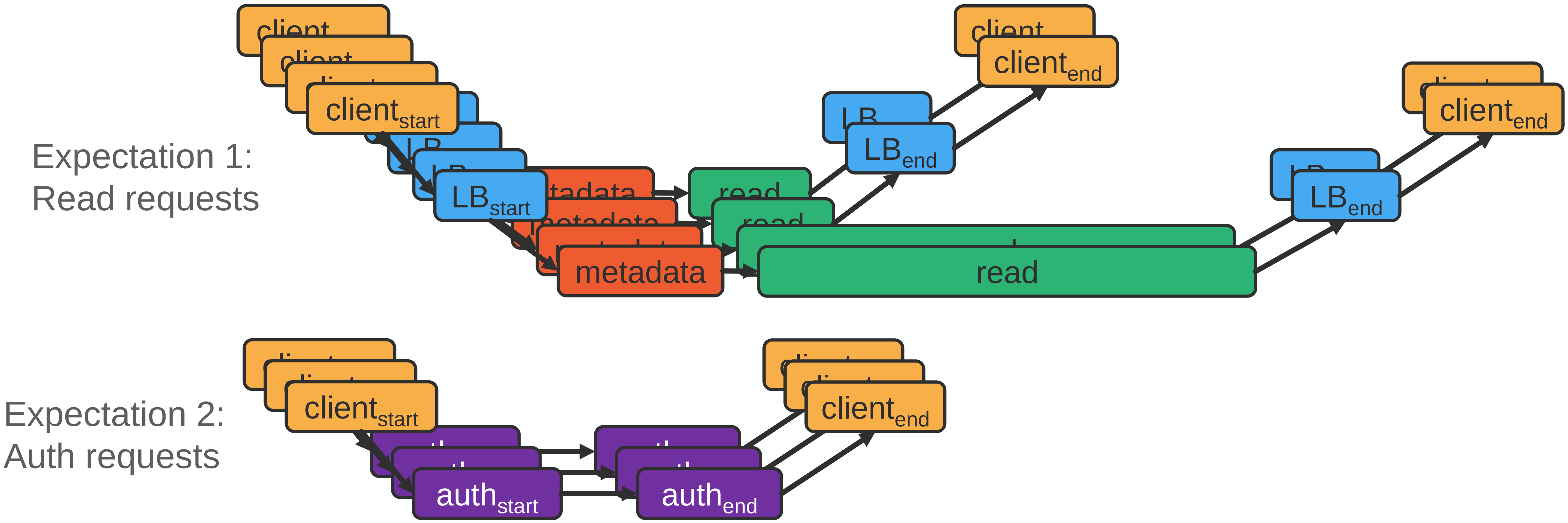


Challenge 1: Grouping

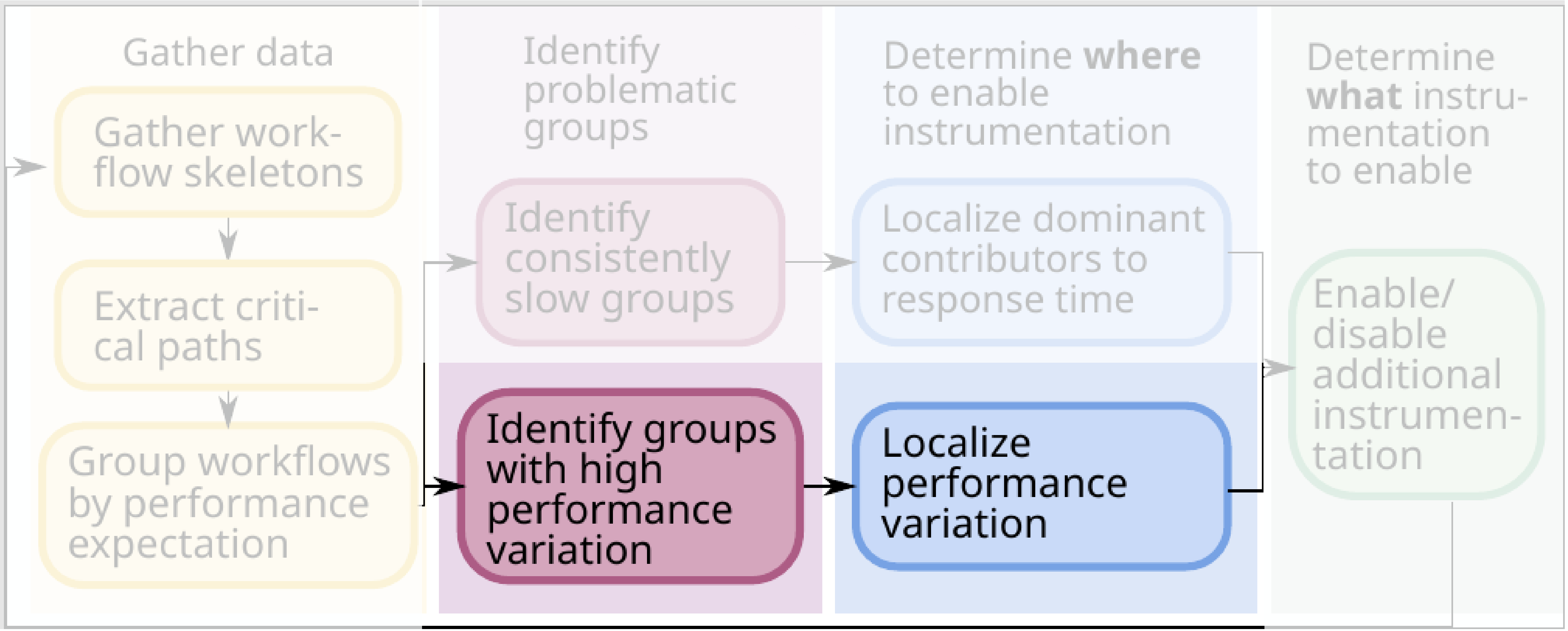


Which Requests are Expected to Perform Similarly

- Depends on the distributed application begin debugged
- Generally applicable: Requests of the same type that access the same services
- Additional app-specific details could be incorporated

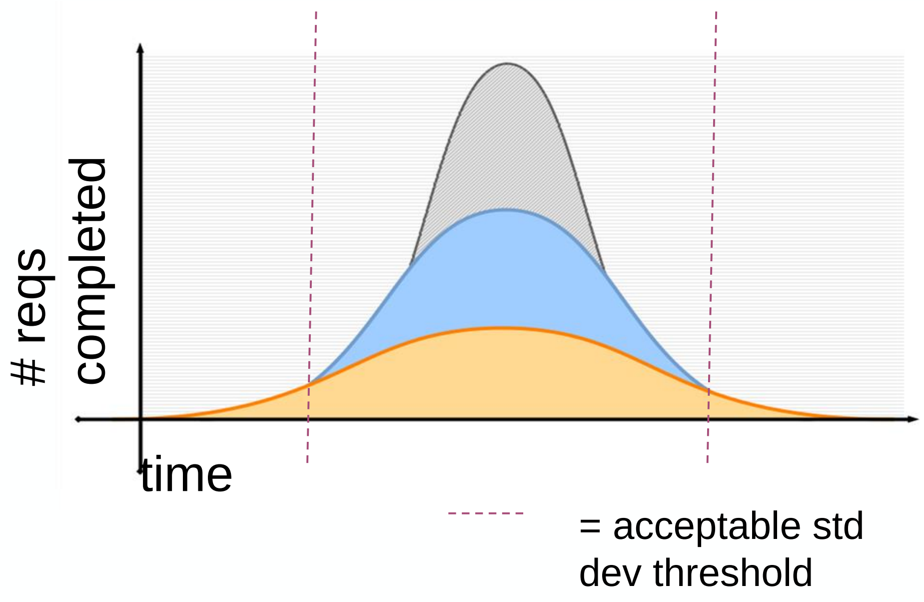


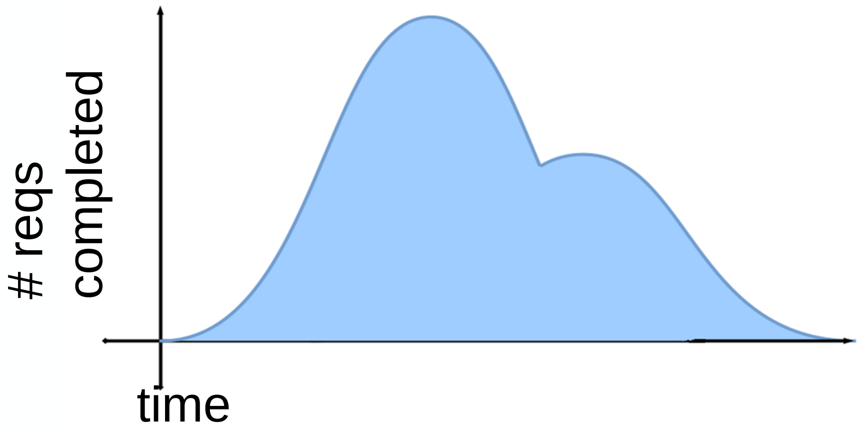
Challenge 2: Localization



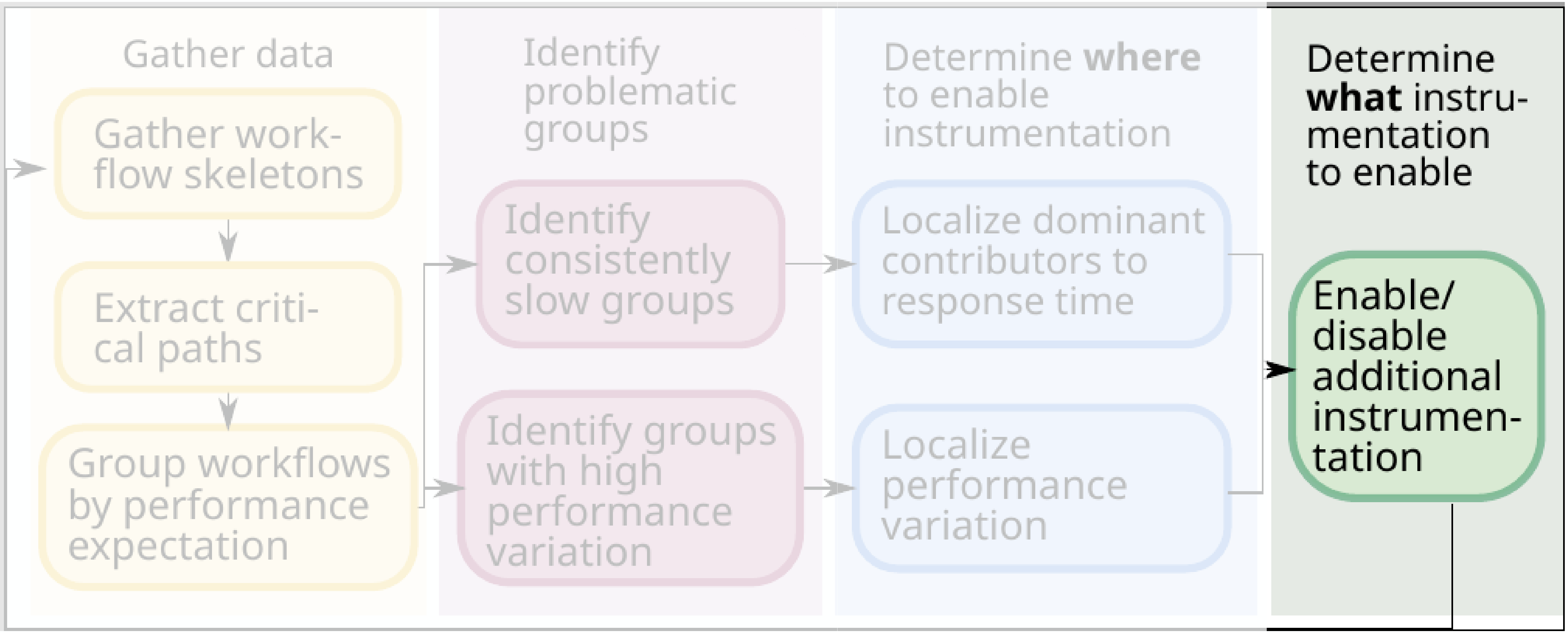
Localizing Performance Variations

- Order groups and edges within groups.
  - How to quantify performance variation?
- Multiple metrics to measure variation
  - Variance/standard deviation
  - Coefficient of variance (std. / mean)
    - Intuitive
    - Very small mean -> very high CoV
  - Multimodality
    - Multiple modes of operation





Challenge 3: What to enable



Search Space

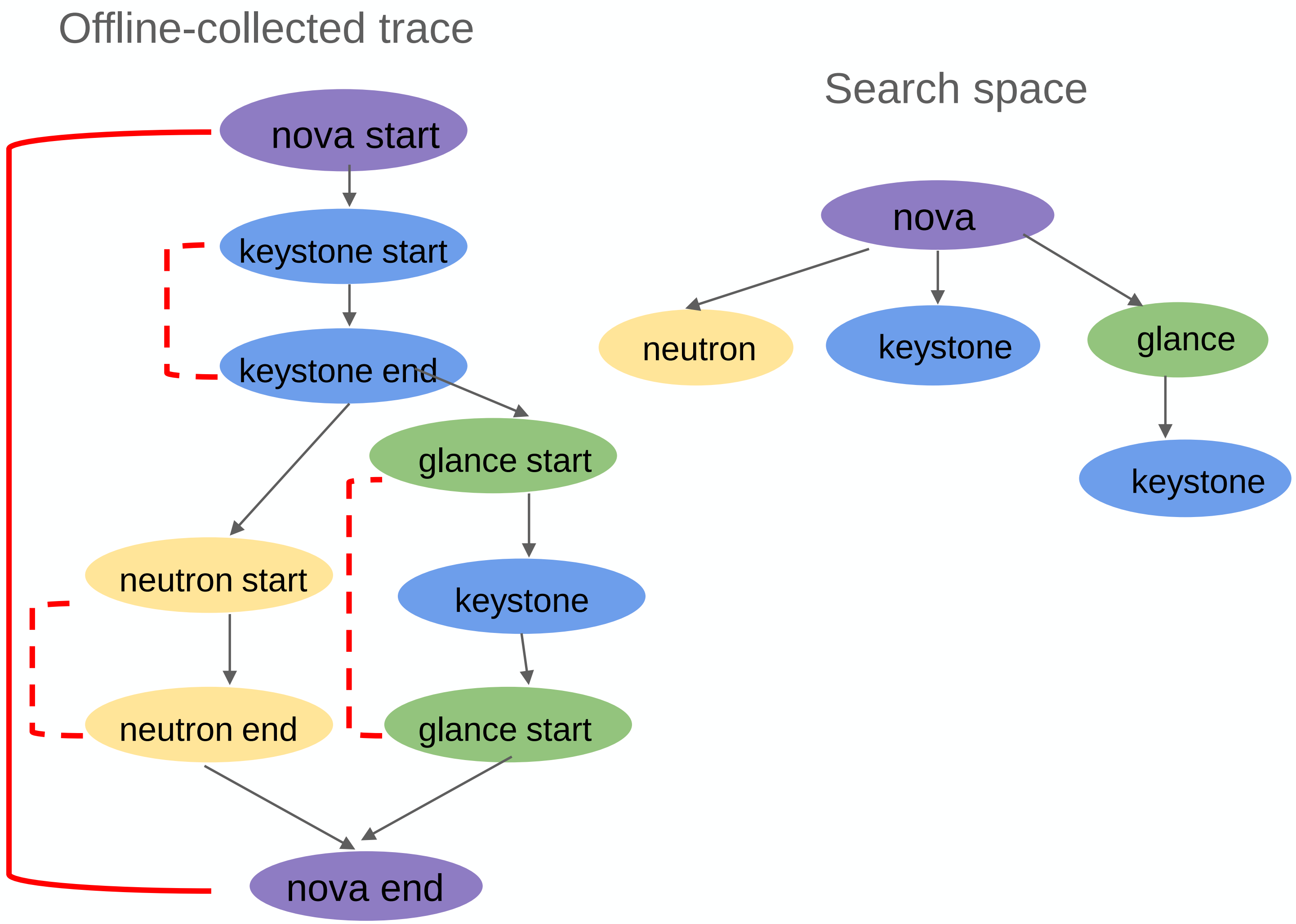
- How to represent all of the instrumentation that Pythia can control?
- How to find relevant next-trace-points after problem is narrowed down?
- Trade-offs:
  - Quick to access
  - Compact
  - Limit spurious instrumentation choices

Search Strategies

- How to explore the search space?
  - Quickly converge on problems
  - Keep instrumentation overhead low
  - Reduce time-to-solution
- Many possible options
  - Pluggable design

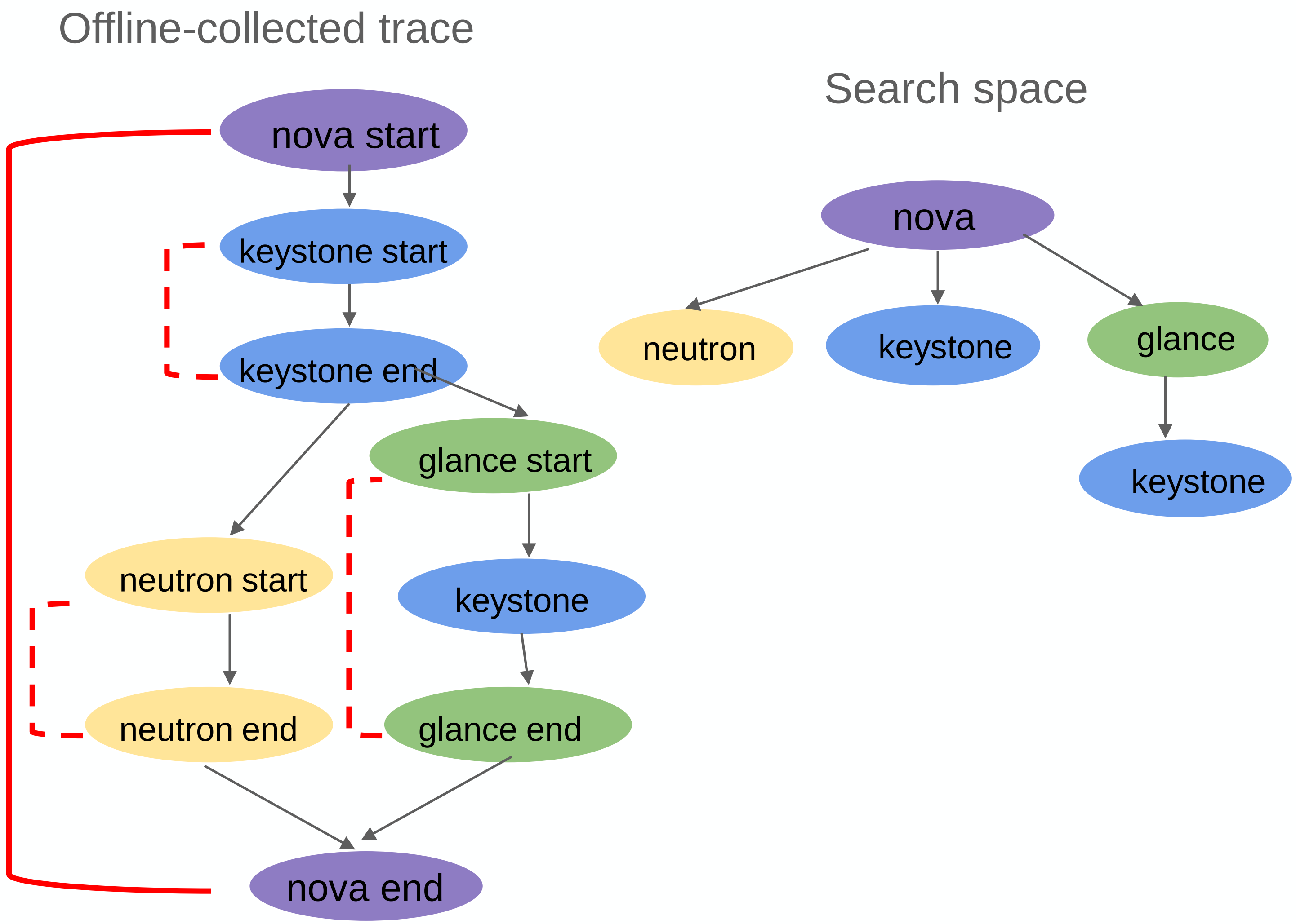
Search Space: Calling Context Trees

- One node for each calling context i.e., stack trace
- Leverages the hierarchy of distributed system architecture
- Construction: offline profiling
- Trade-offs
  - Quick to access
  - Compact
  - Limit spurious instrumentation choices



Search Strategy: Hierarchical Search

- One of many choices
- Search trace point choices top-down
- Very compatible with Calling Context Trees



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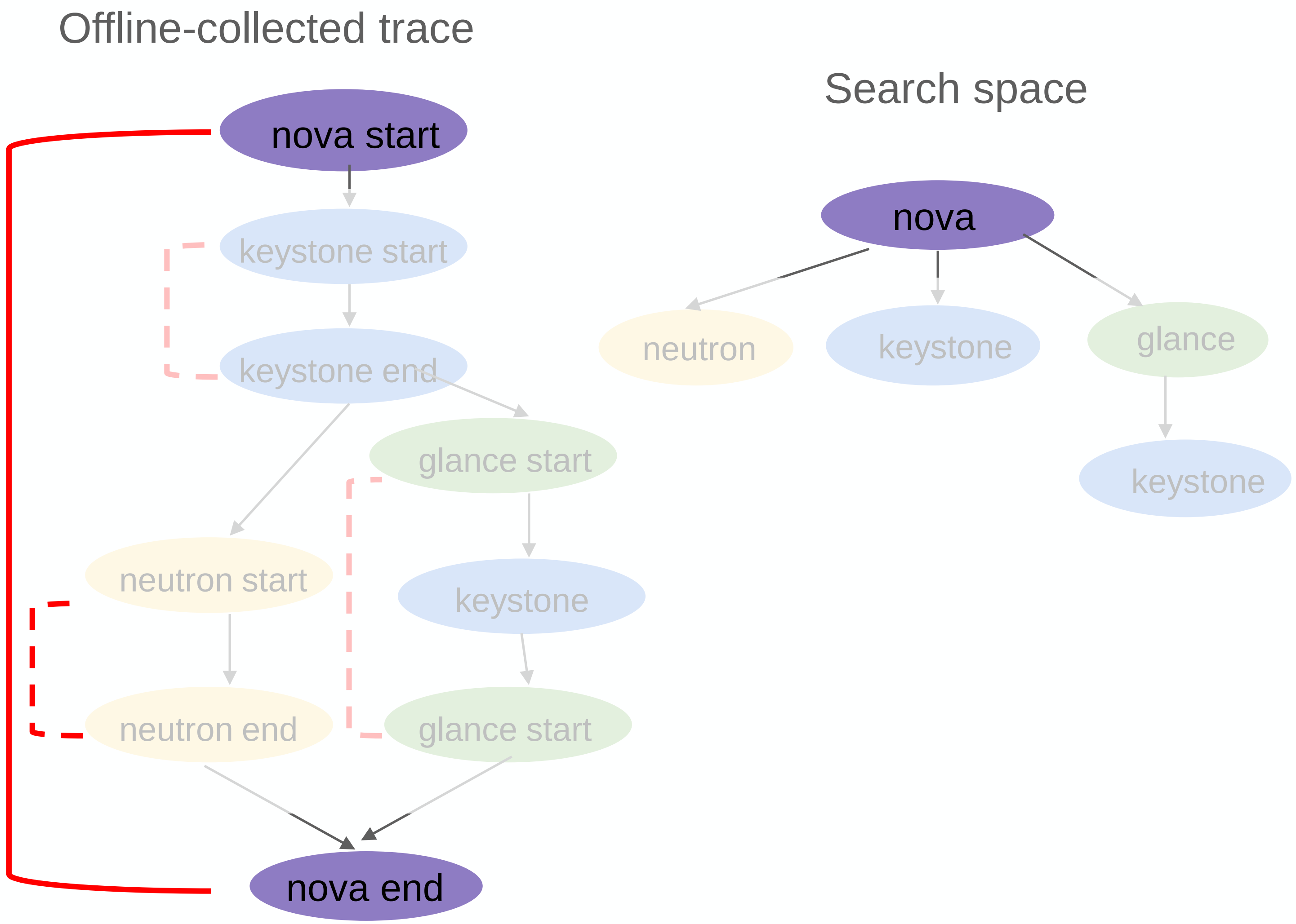

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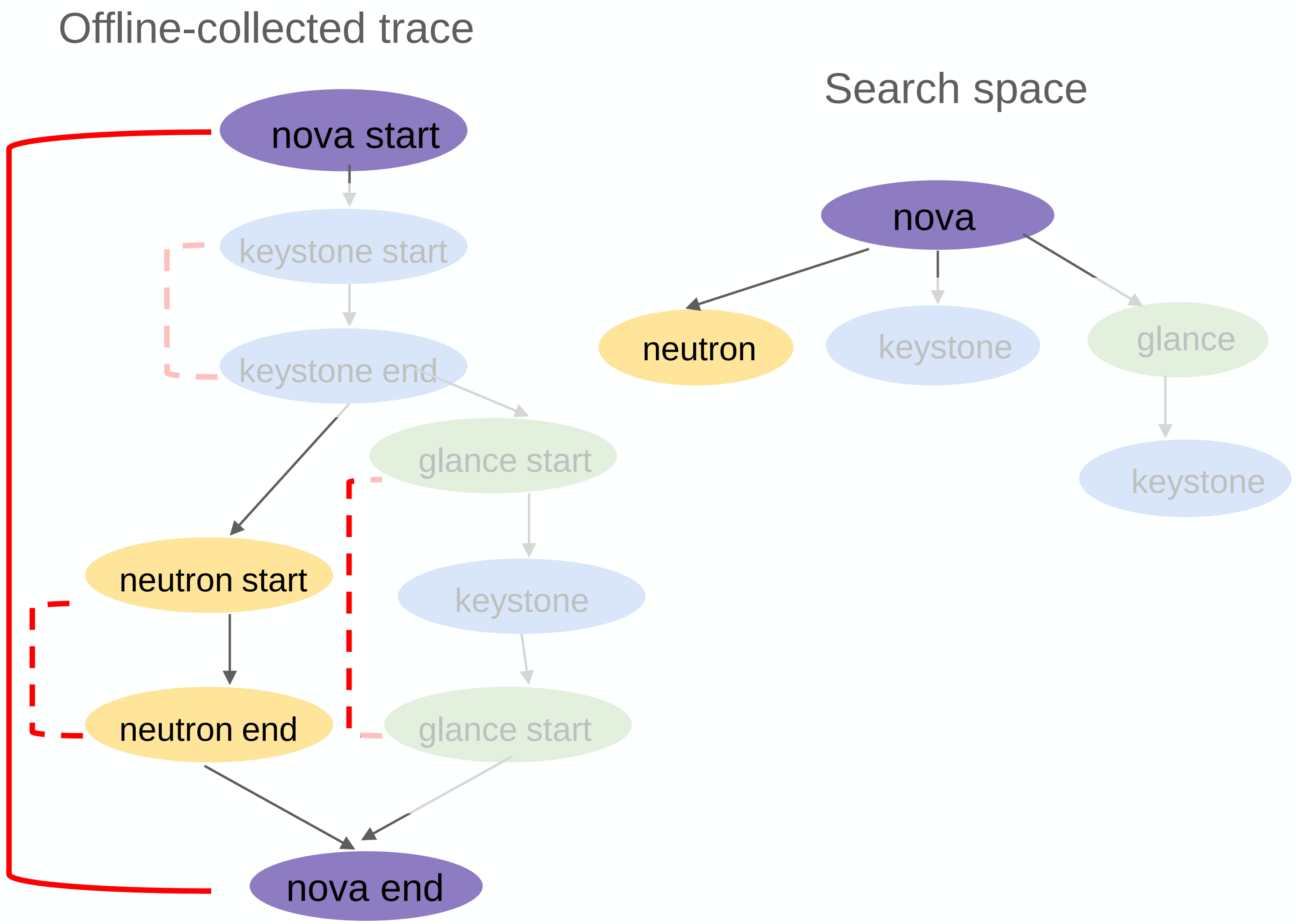

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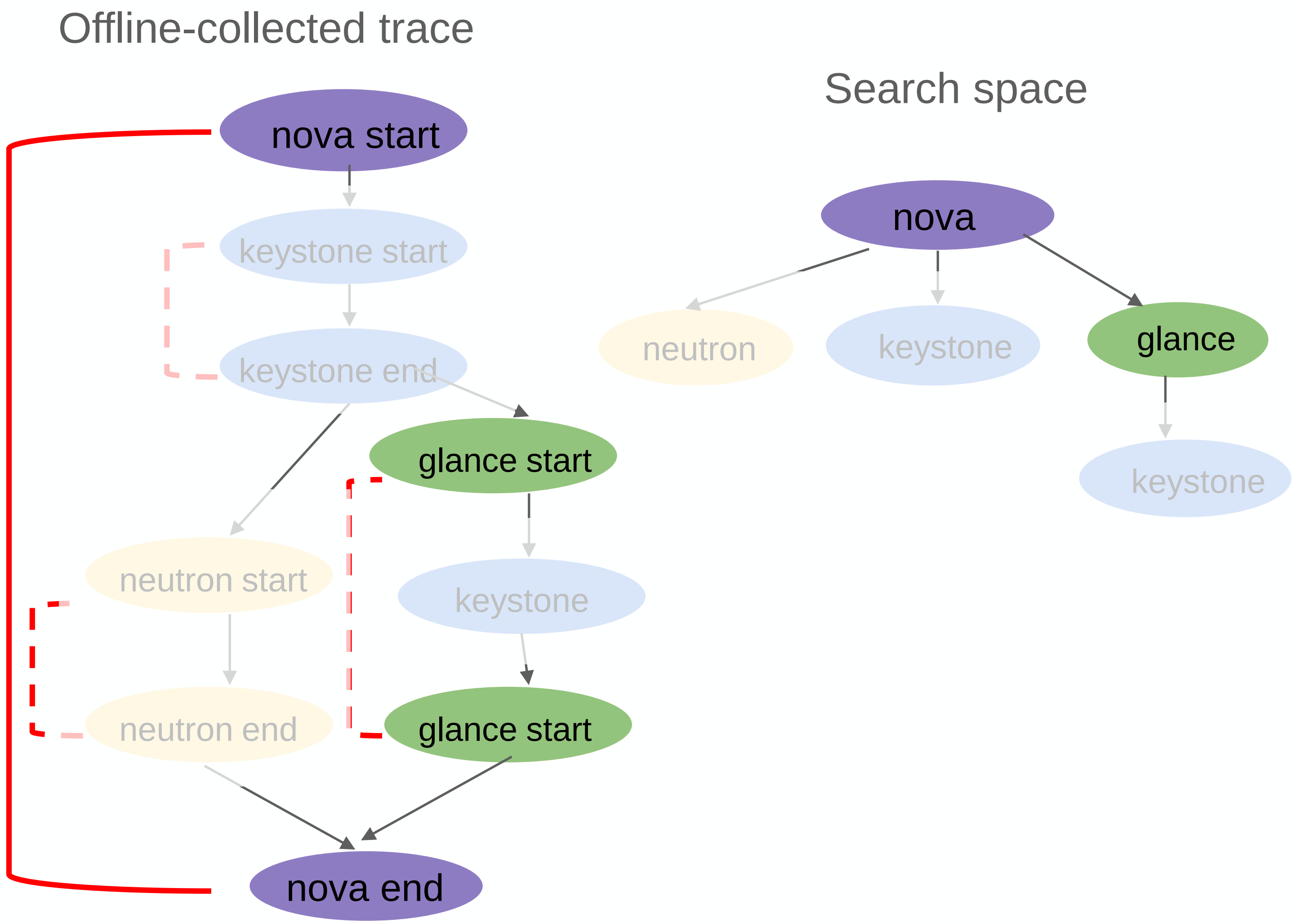

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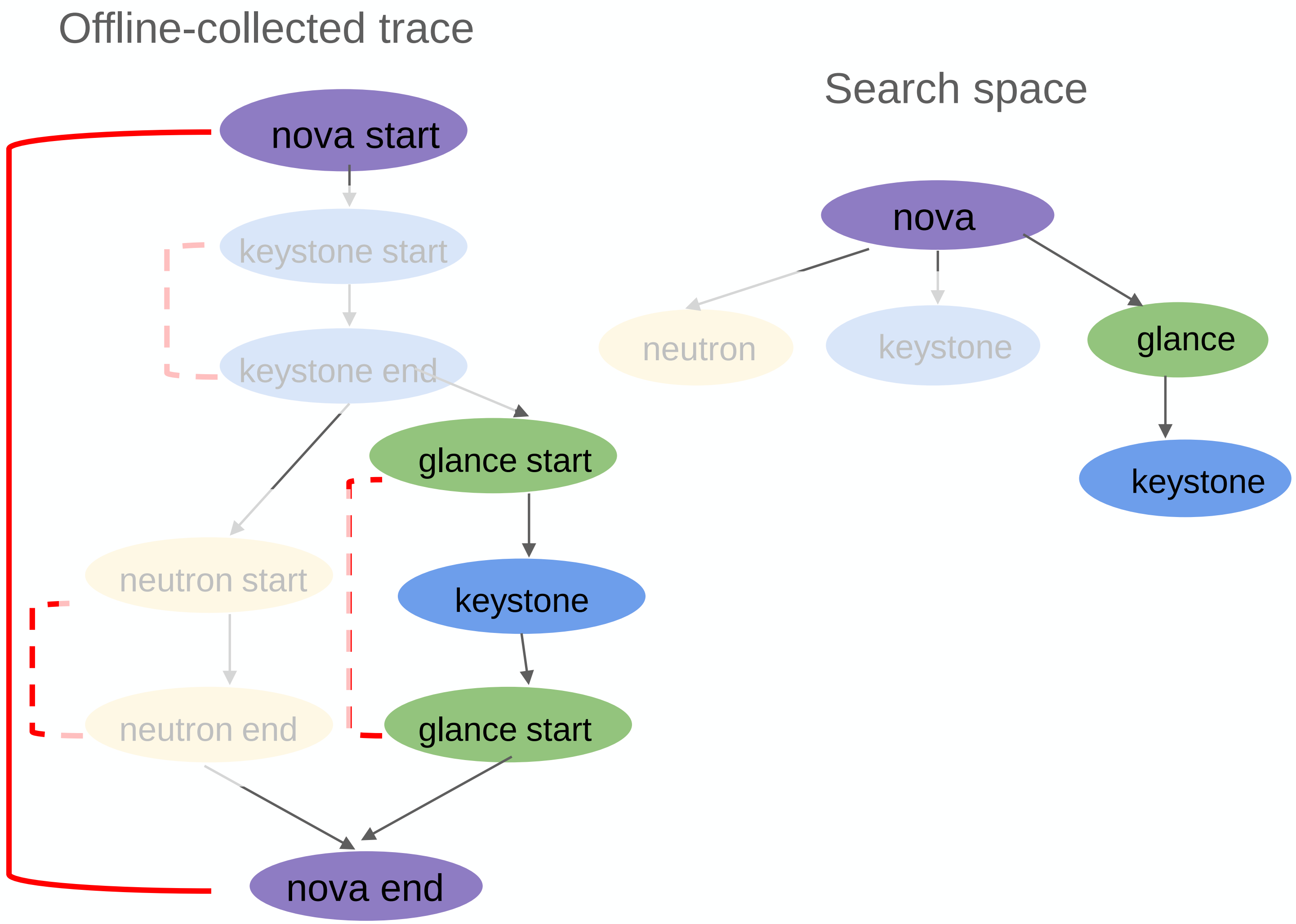


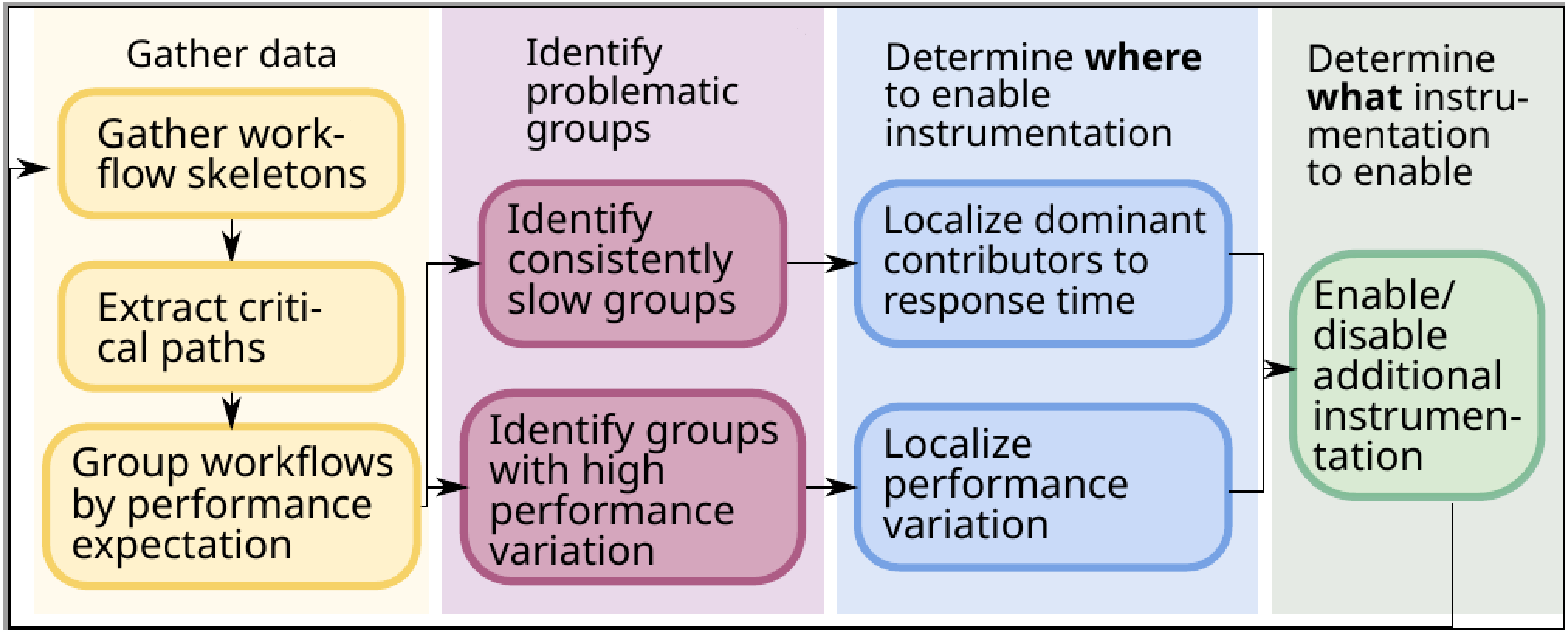
Explaining Variation Using Key-Value Pairs in Trace Points

- Canonical Correlation Analysis (CCA)
- Used to find important key-value pairs in the traces

$$a' = \max_{a} corr(a^T X, Y)$$

$Y = (t_1, t_2, \ldots, t_n)$ the request durations
$X = (x_1, x_2, \ldots, x_m)$ the collected variables
$a' \in \mathbb{R}^m$ the coefficients indicating most correlated variables

Vision of Pythia – Completing the Cycle

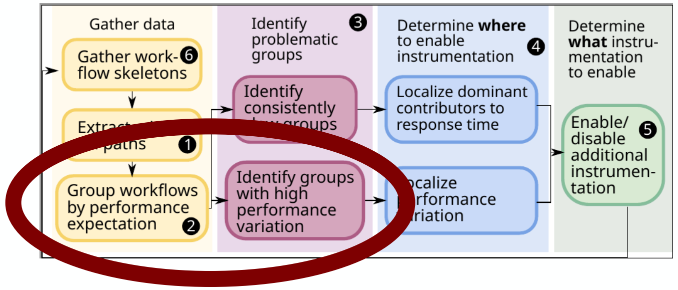


Validating Pythia’s Approach

- Can performance variation guide instrumentation choices?
- Run exploratory analysis for OpenStack
  - Start with default instrumentation
  - Localize performance variation
  - Find next instrumentation to enable
  - Use CCA for finding important key-value pairs

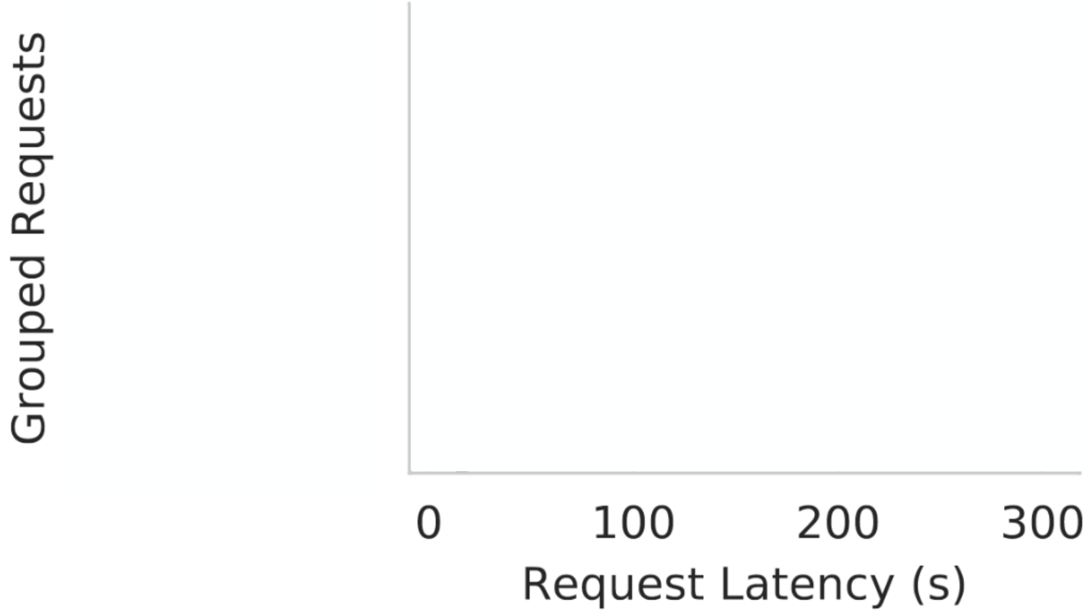
Validating Pythia’s Approach - Setup

- **OpenStack:** an open source cloud platform, written in Python
- **OSProfiler:** OpenStack’s tracing framework
  - We implemented controllable trace points
  - Store more variables such as queue lengths
- Running on MOC
  - 8 vCPUs, 32 GB memory
- Workload
  - 9 request types, VM/floating IP/volume create/list/delete
  - Simultaneously execute 20 workloads

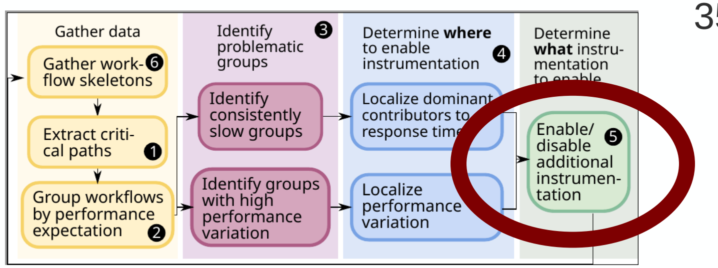


Step 1: Grouping & Localization

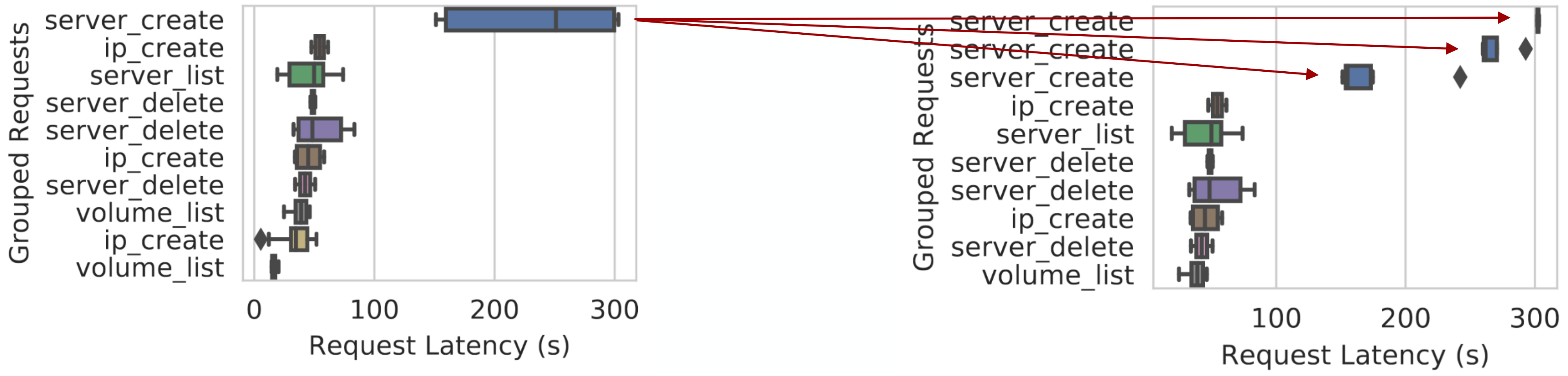
- Collect latency values for each request
- Grouping: Same request type with same trace points
- Server create requests have unusually high variance and latency
- Pythia would focus on this group



Step 2: Enable additional instrumentation



Groups with different queue lengths



- Pythia localizes variation into a semaphore in server create
- After adding queue length variable into traces, we see 3 distinct latency groups
  - CCA also finds this variable important

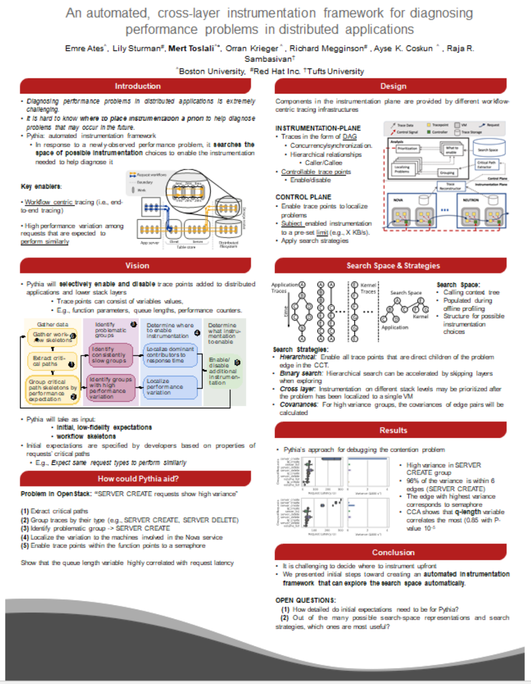
TAKEAWAY: Pythia's approach identifies the instrumentation needed to debug this problem

Open Questions

- What is the ideal structure of the search space? What are possible search strategies? What are the trade-offs?
- How can we formulate and choose an “instrumentation budget”?
- How granular should the performance expectations be?
- How can we integrate multiple stack layers into Pythia?

More in the paper

- Pythia architecture
- Problem scenarios
- Instrumentation plane requirements
- Cross-layer instrumentation



- It is very difficult to debug distributed systems
- Automating instrumentation choice is a promising solution to overcome this difficulty

Concluding Remarks

More info in our paper (bu.edu/peaclab/publications)

Please send feedback to ates@bu.edu
or join us at the poster sesion