# Metastable Failures in the Wild

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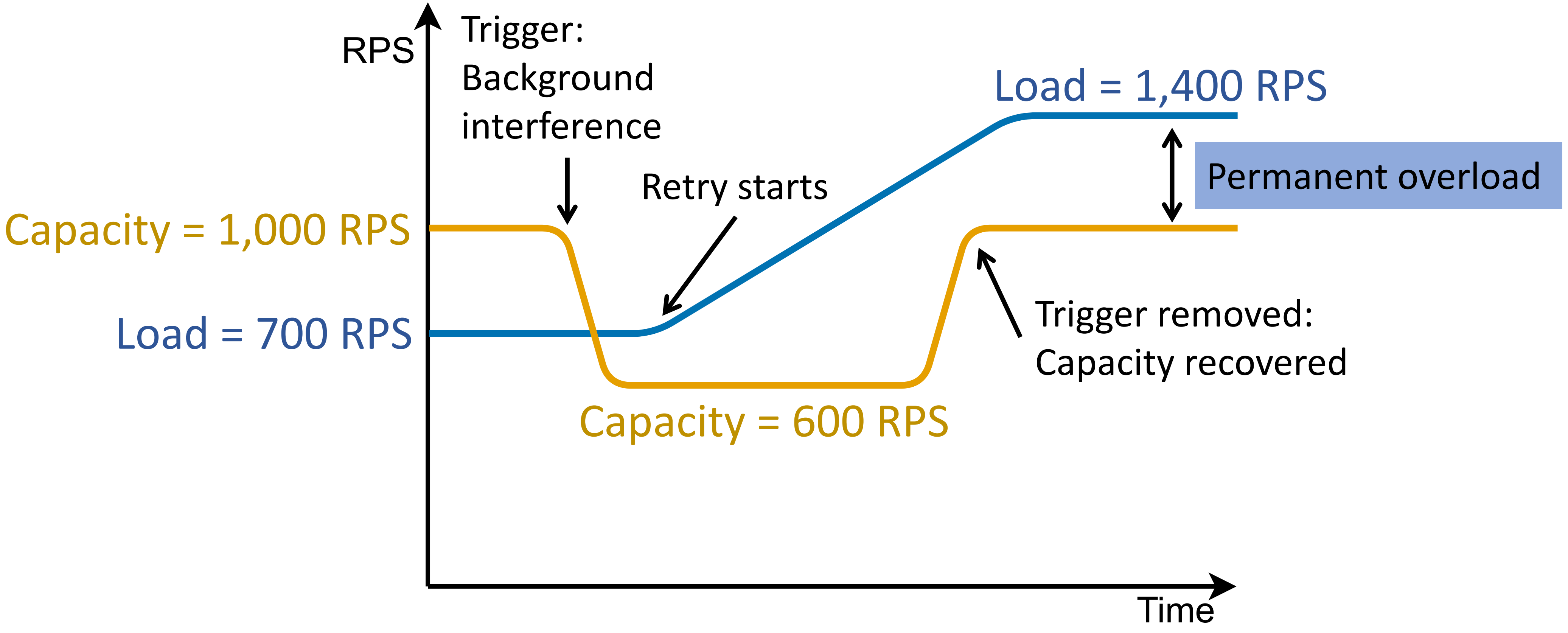
3

*Equal contribution

# What are Metastable Failures?

- Example: Retry Storm




**Takeaway: Permanent overload even after the trigger is removed**

# Metastable Failures are Prevalent

- Can be catastrophic
  - E.g., 4 out of 15 major outages in the last decade at AWS
- Ad-hoc diagnosis
  - Persistent congestion
  - Persistent overload
  - Retry storms
  - Death spirals
  - etc.
- Ad-hoc recovery
  - Load-shedding
  - Rebooting
  - Adding more resources
  - Tweaking configurations

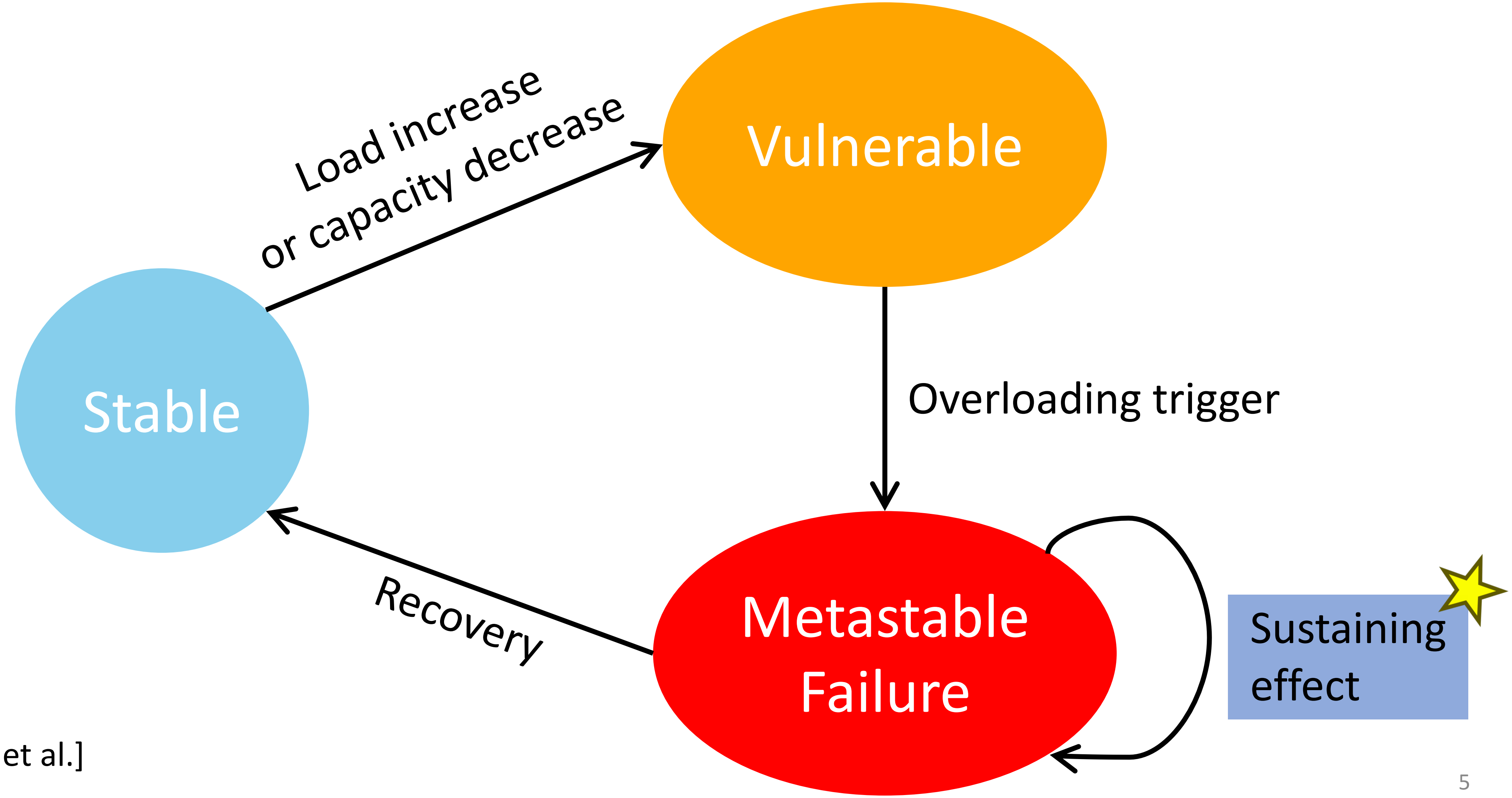
**Insight: These different-looking failures can be characterized under one taxonomy**

# Metastability in the Wild – Survey

- We search through over 600 public post-mortem incident reports
  - Identify 21 metastable failures in
    - Large cloud infrastructure providers
    - Smaller companies and projects

- Can cause major outages
  - 4-10 hours most commonly
  - Incorrect handling leads to future incidents
  - An important class of failures to study

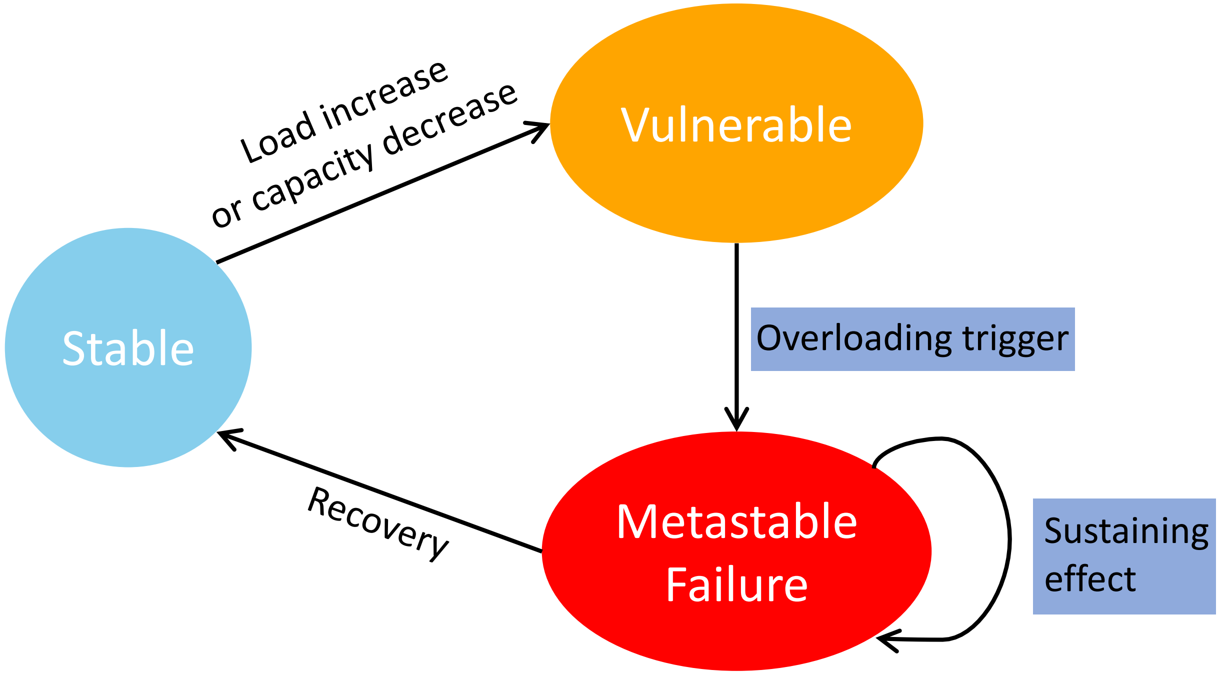
# Defining Metastability – System States




[Bronson et al.]

# Survey Summary

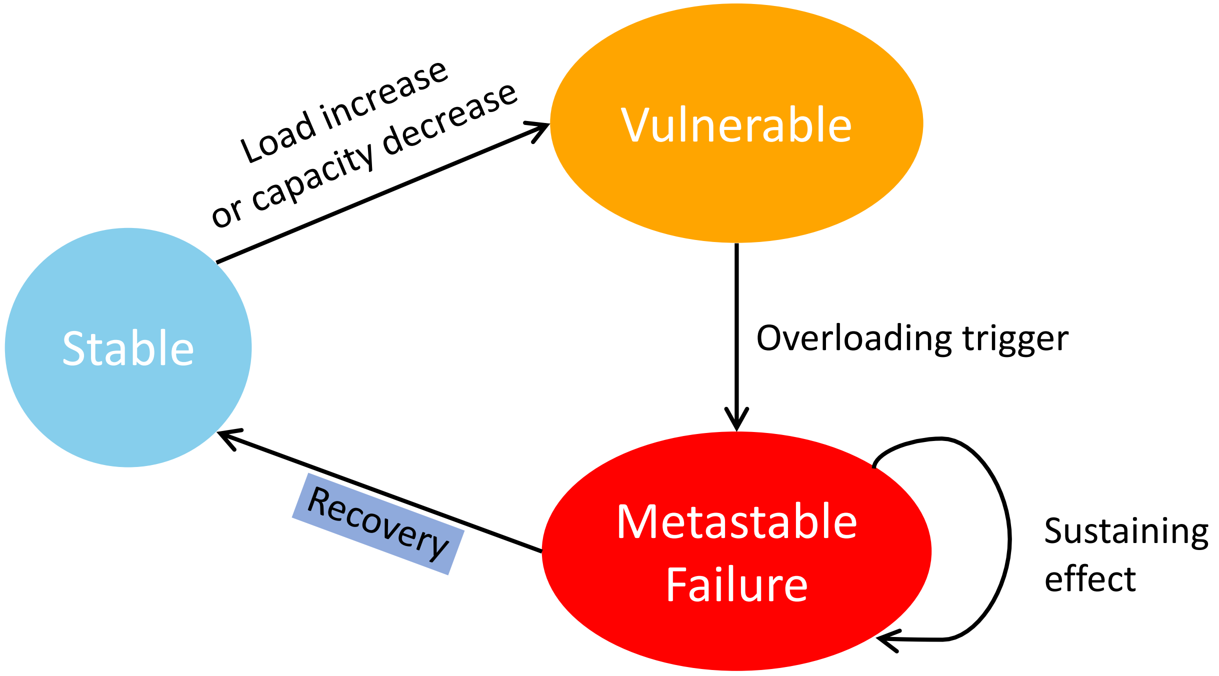
- Triggers
  - About 45% are due to engineer errors
    - Buggy configuration or code deployments
    - Latent bugs
  - About 35% are due to load spikes
  - 45% involve multiple triggers




- Sustaining effects
  - Load increase due to retries (over 50%)
  - Expensive error handling
  - Lock contention
  - Performance degradation due to leader election churn

# Survey Summary

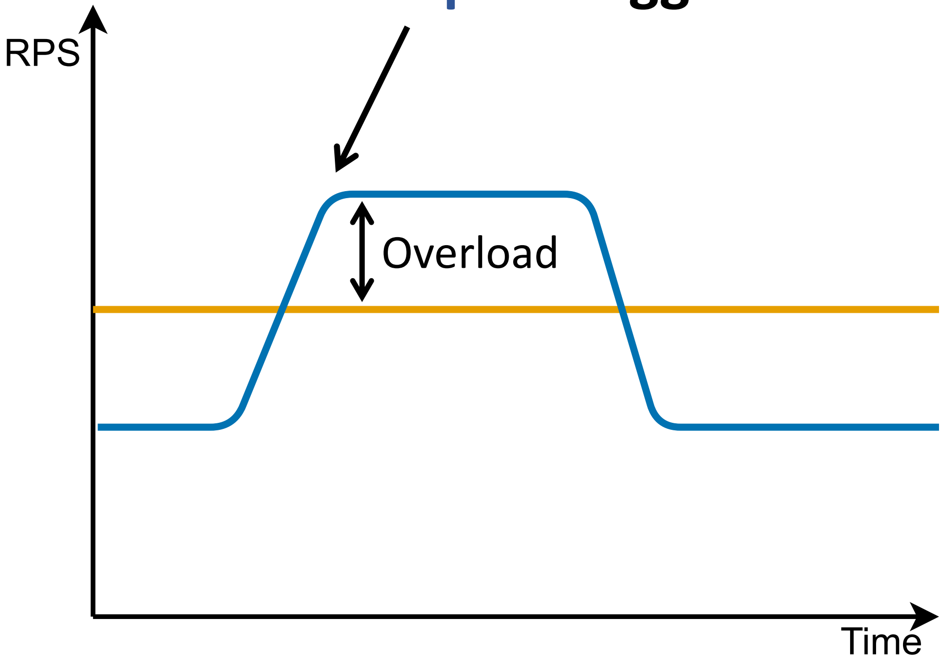
- Recovery
  - Direct load-shedding
    - Throttling
    - Dropping requests
    - Changing workload parameters
  - Indirect load-shedding
    - Reboots
    - Policy changes



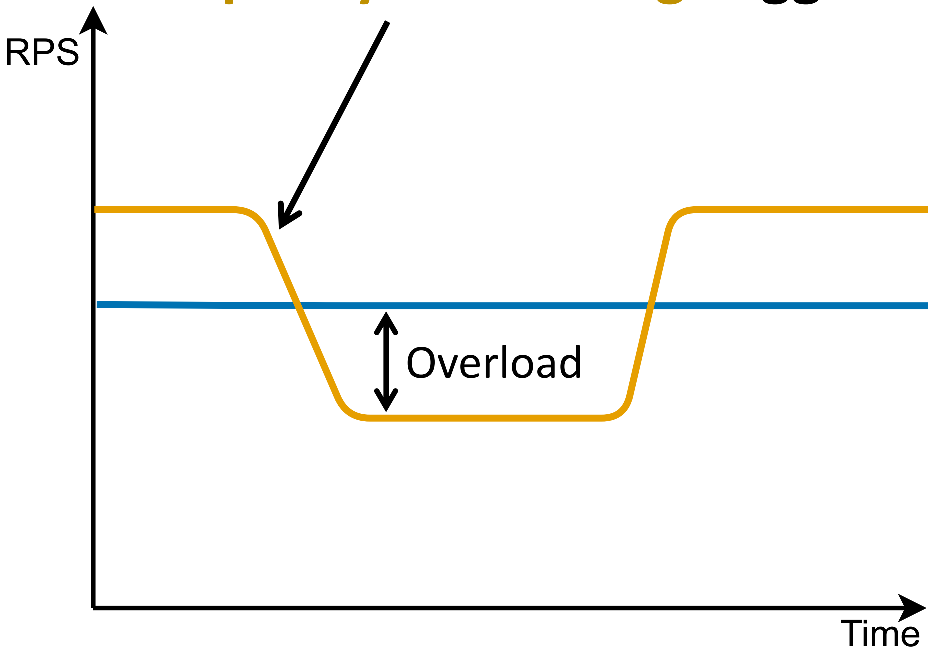
# Metastability Taxonomy – Trigger

- One or more events that overload the system
- Two types:

**Load-spike trigger**



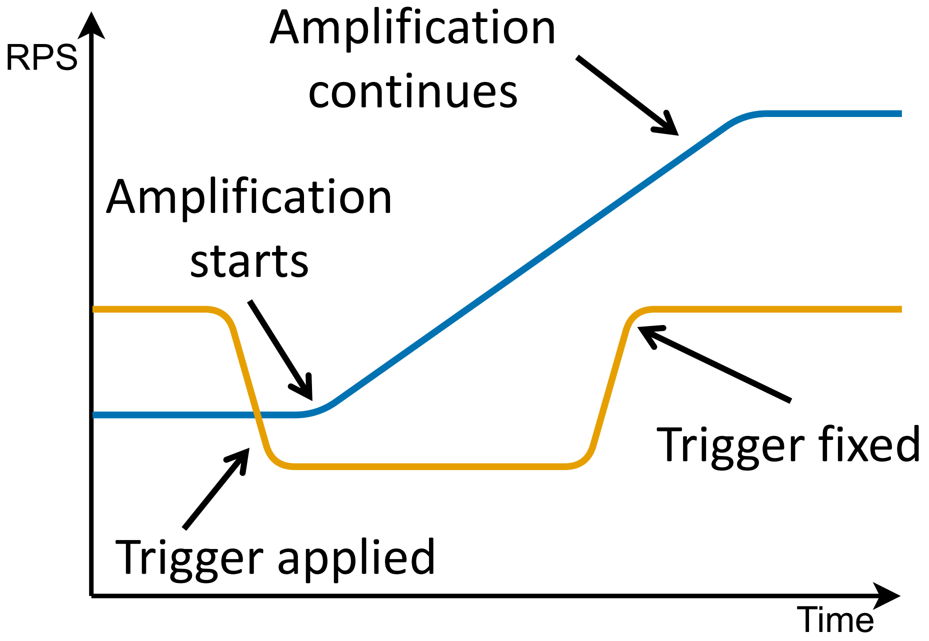

**Capacity-decreasing trigger**



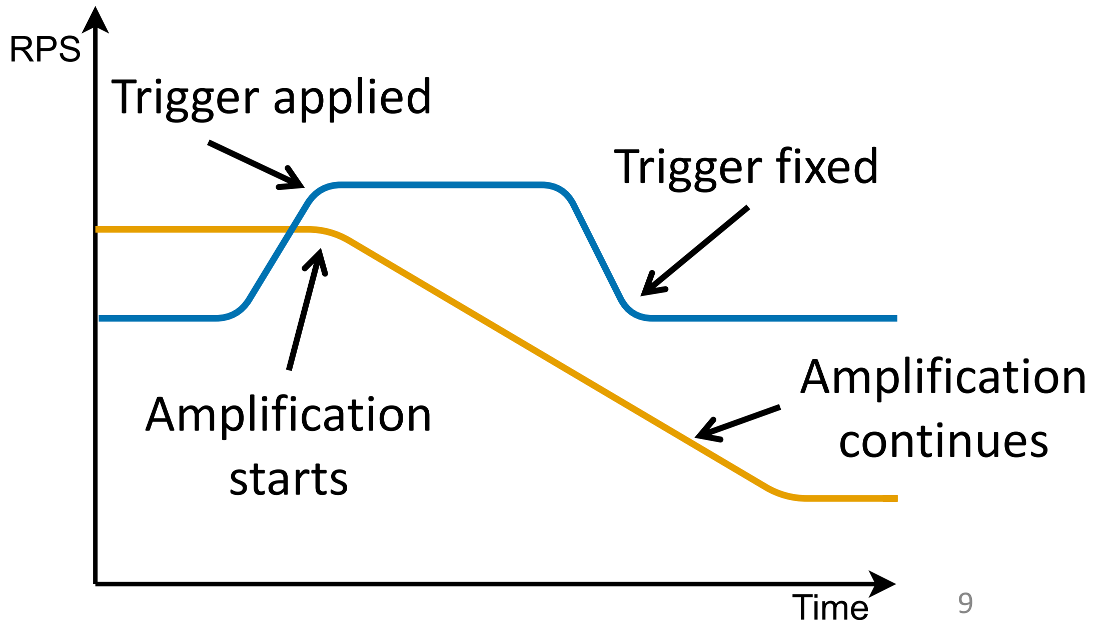
# Metastability Taxonomy – Sustaining effect

- A feedback loop that keeps the system overloaded
- Two types:

**Workload amplification**




**Capacity degradation amplification**

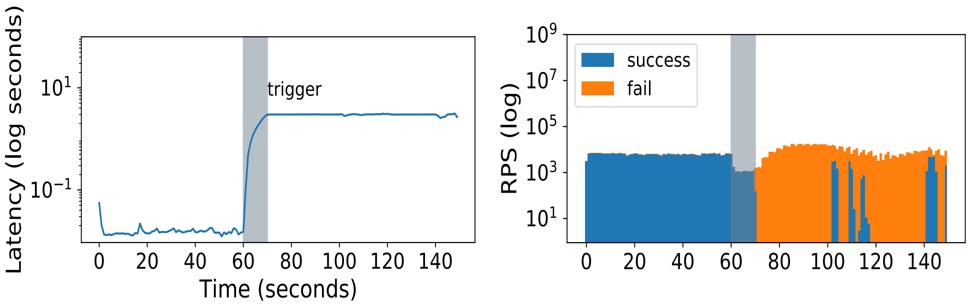


# Four Metastability Scenarios

**Load-spike trigger** | **Capacity-decreasing trigger**

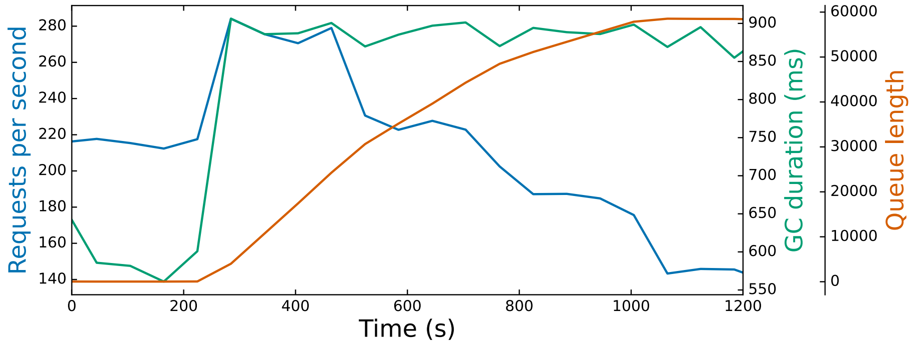
**Workload amplification**

Common incidents due to retries in the survey

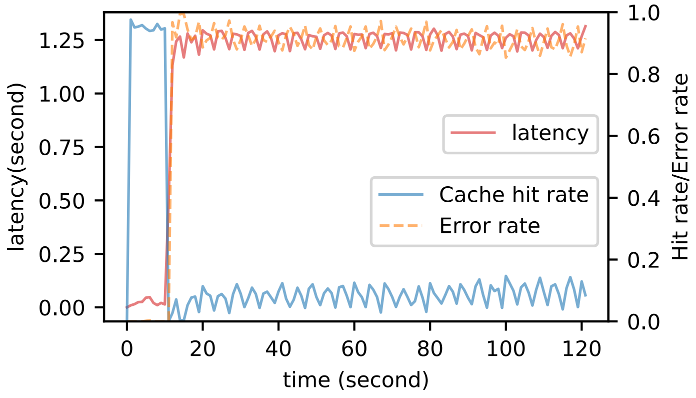



Replicated State Machine

**Capacity degradation amplification**




Garbage Collection (GC)




Look-aside Cache

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**Workload amplification**

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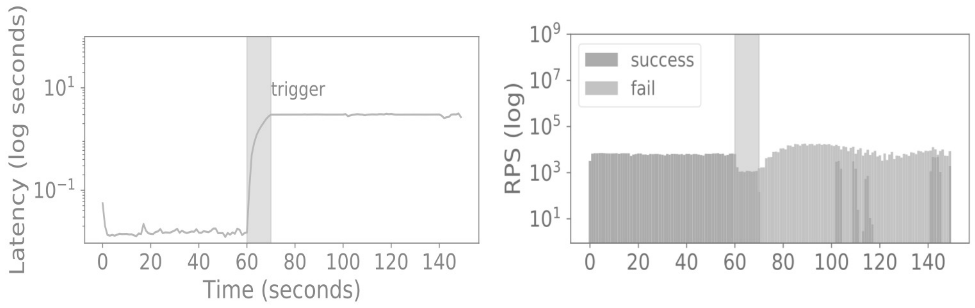


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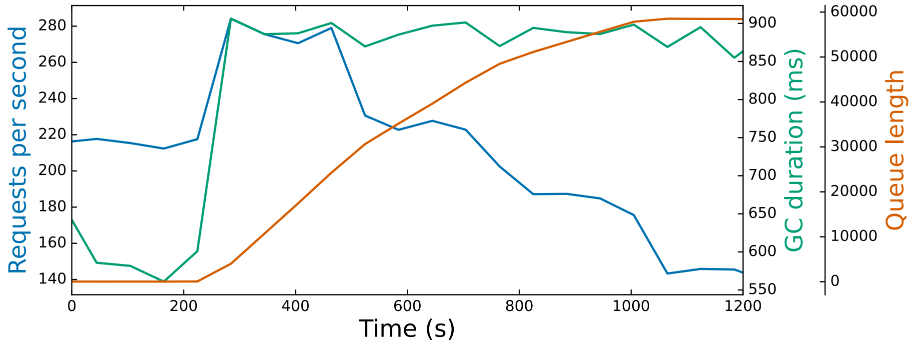


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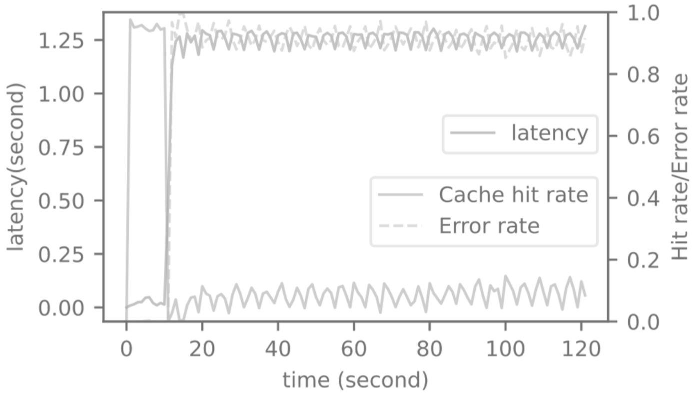



Look-aside Cache

# Metastability due to GC – Sustaining Effect

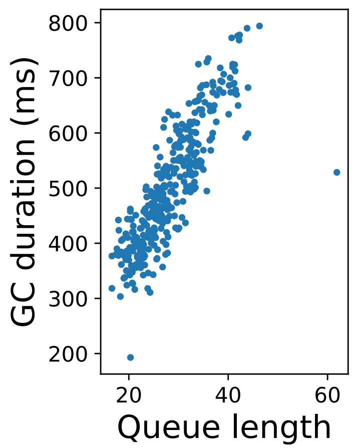
Load-spike

High queue length

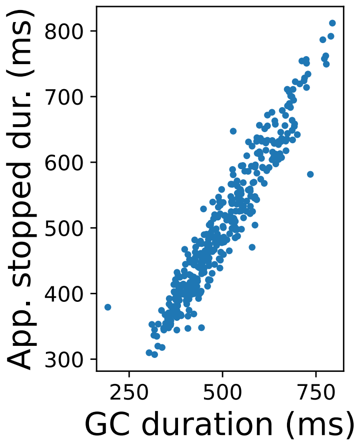
**Capacity degradation amplification**

High GC behavior

Job processing slows down




- More active objects to process during a GC cycle
- Higher memory pressure causes more GC cycles

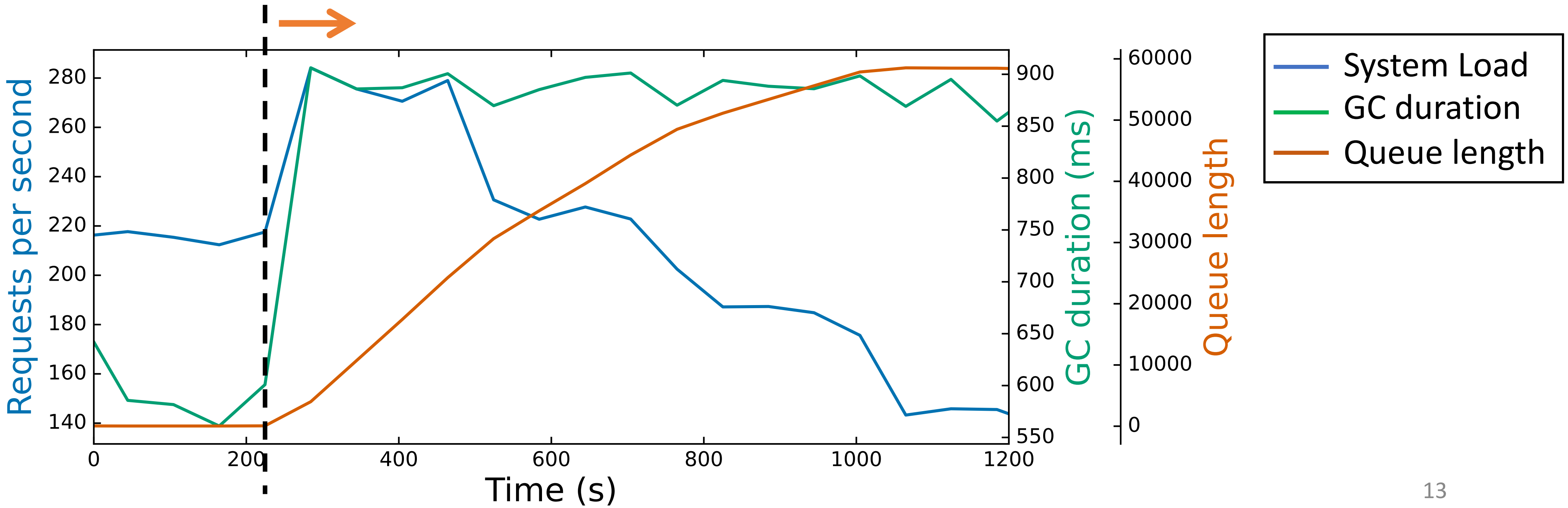



- GC causes application to pause and slow down

**Sustaining effect: Contention between arriving traffic and GC consuming resources**

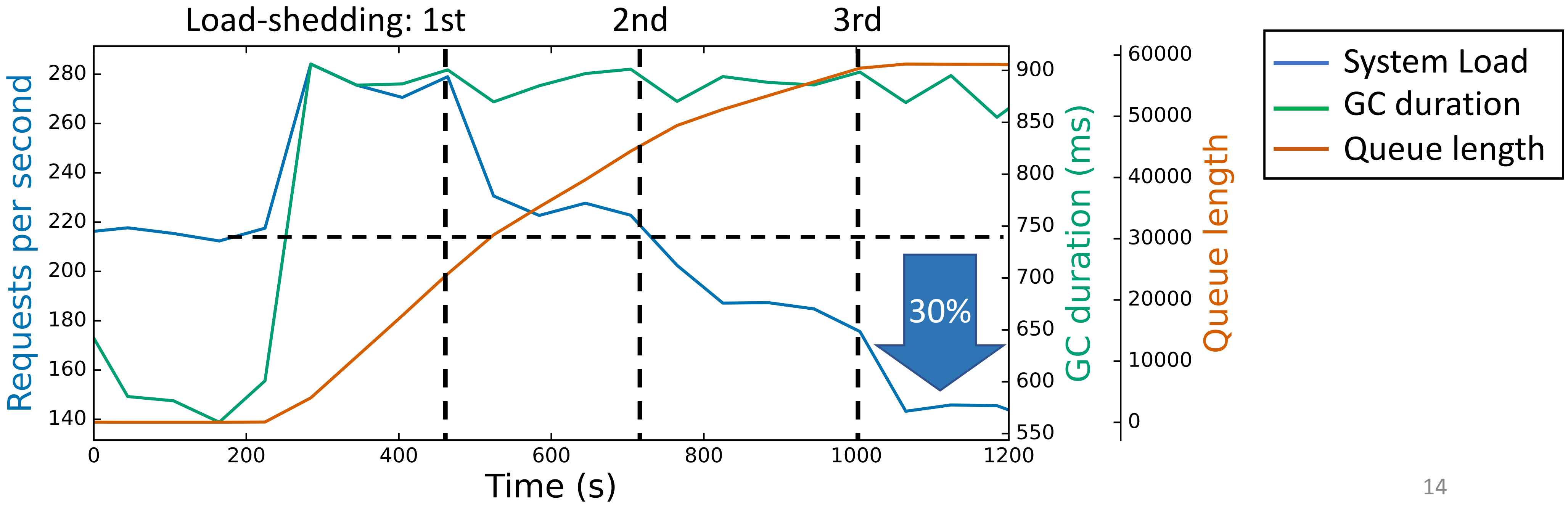
# Metastability due to GC – Timeseries

- Load-spike triggers high queue length and high GC behavior
- Queue continues building up



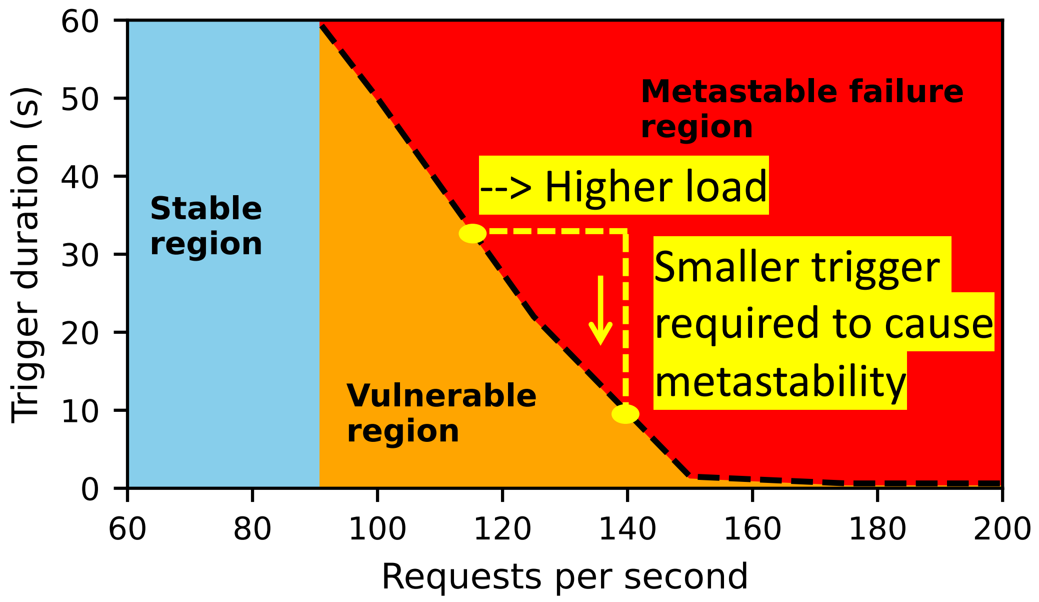
# Metastability due to GC – Timeseries

- Load-spike triggers high queue length and high GC behavior
- Queue continues building up
- Aggressive load-shedding does not lower the GC behavior



# Degrees of Vulnerabilities

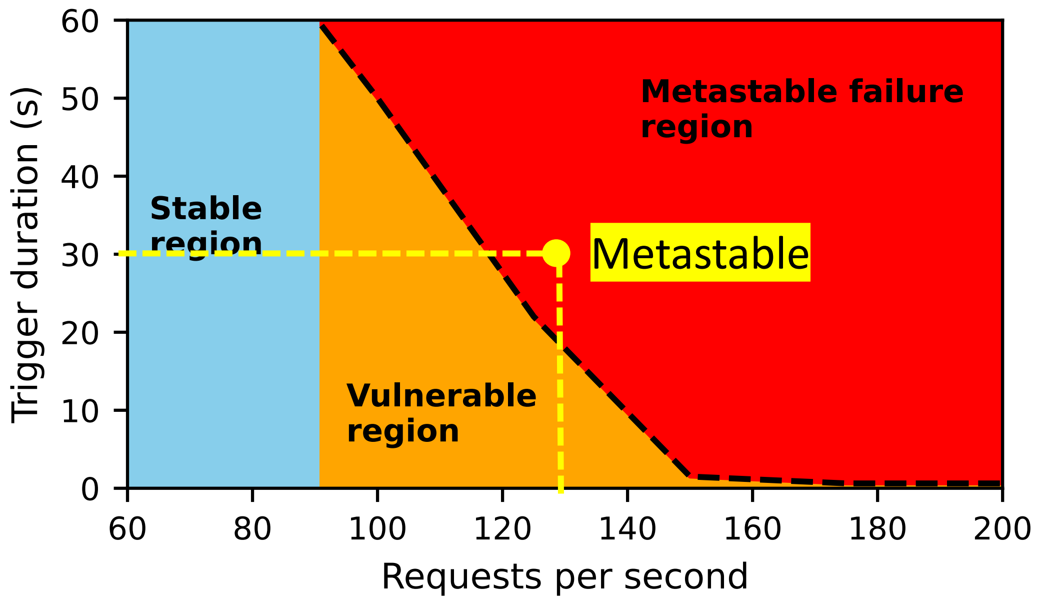
- **System load** determines vulnerability
  - Tradeoff: Efficiency vs. Vulnerability




Max heap size = **256** MB

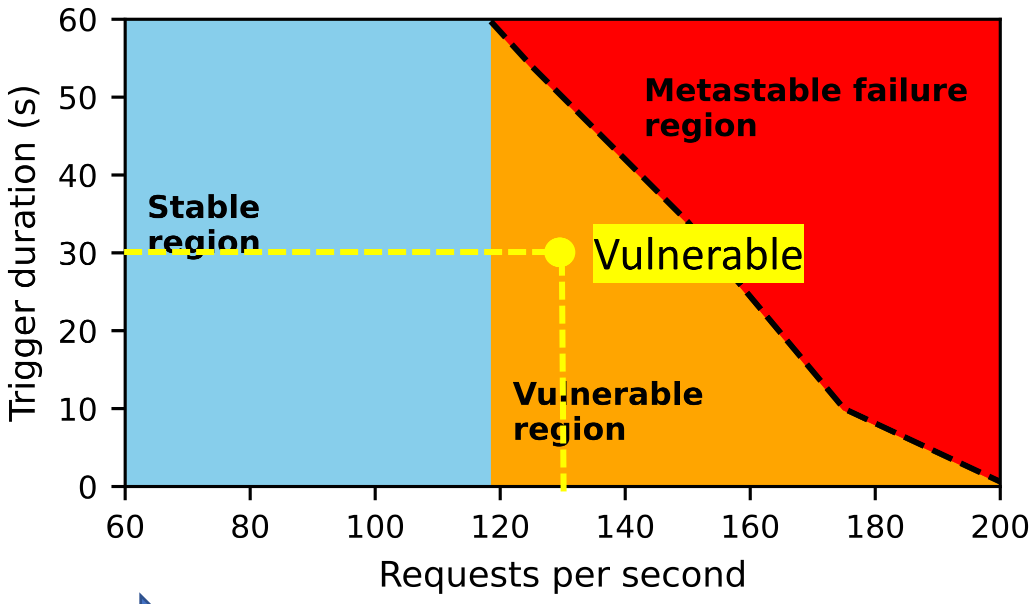
# Degrees of Vulnerabilities

- **System load** determines vulnerability
  - Tradeoff: Efficiency vs. Vulnerability
- **System configs** impact vulnerability
  - Larger memory → Lower vulnerability




Max heap size = **256** MB

Increase memory size




Max heap size = **384** MB

# Lessons

- **Detect and react to trigger quickly to avoid metastable failures**
  - Sustaining effects may not be immediate
  - Sustaining effects take time to amplify the overload

- **Design systems to eliminate/minimize sustaining effects**
  - Common case optimizations may cause or exacerbate sustaining effect

    → Might not be possible to eliminate sustaining effect entirely

    → Consider the slow path, not just the fast path

# Lessons

- **Understand the degree of vulnerability of the system to control risk**
  - System load and capacity determines vulnerability
    - →Load testing can reveal issues
    - →Adding capacity can lower vulnerability
  - System config affects vulnerability
    - →Control relevant configs to lower vulnerability

# Lessons

- **Recover from metastable failure by breaking the sustaining effect cycle**
  - Fix the triggers to prevent recurrence
    - Negate load spikes by load shedding
    - Rollback or halt deployments
    - Hot-fix software bugs
  - End the overload to break the sustaining effect cycle
    - Load-shedding (e.g., admission control, graceful degradation)
    - Increase capacity
    - Change policy to reduce amplification factors

# Conclusion

- **Metastable failure** – permanent overload even after triggers are removed
- They are prevalent and can **cause major outages**
- Understanding the **sustaining effects** and the **degree of vulnerability** in systems is critical to prevent metastable failures
- Three open-sourced metastable failure examples *https://github.com/lexiangh/Metastability*

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