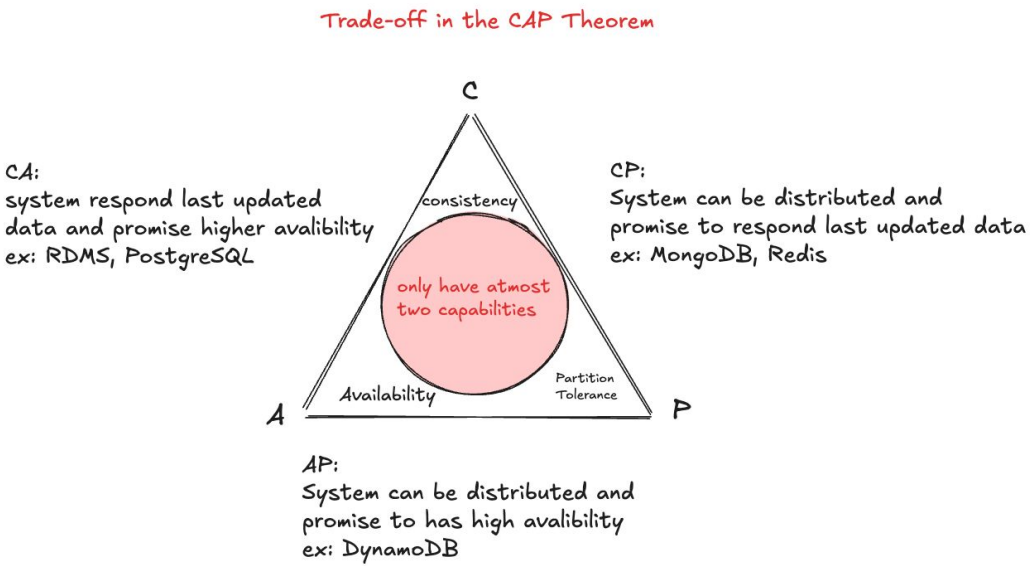
Midterm Mastery

Rong Huang

Part 1 — Topics Enjoyed Learning

The CAP Theorem

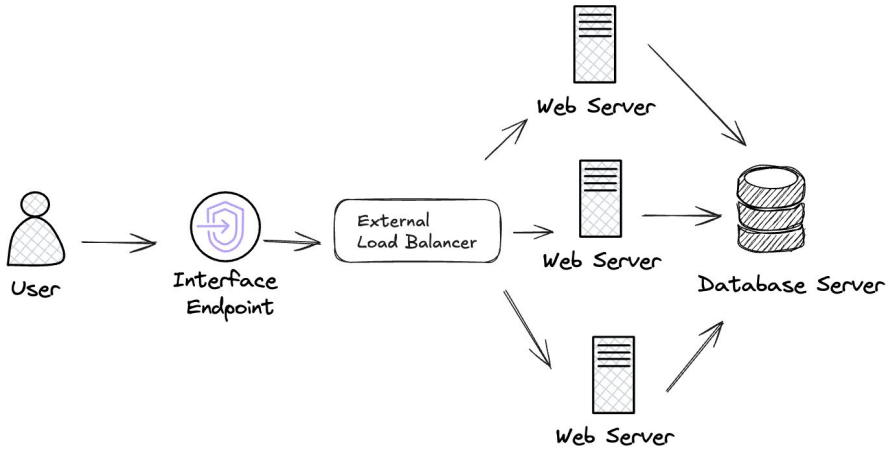


- CAP Theorem states that a distributed system **cannot simultaneously guarantee**:
  Consistency, **Availability**, and **Partition Tolerance**.
- Engineers must **prioritize two** depending on system requirements.
- **CP Systems:** Banking databases (HBase, MongoDB, Redis) – correctness under network partitions.
- **AP Systems:** Caches or social feeds (Cassandra, DynamoDB) – availability despite temporary inconsistency.
  CA Systems: RDBMS / PostgreSQL – suited for single-region or non-partitioned contexts.

Part 1 — Topics Enjoyed Learning

Load Balancing

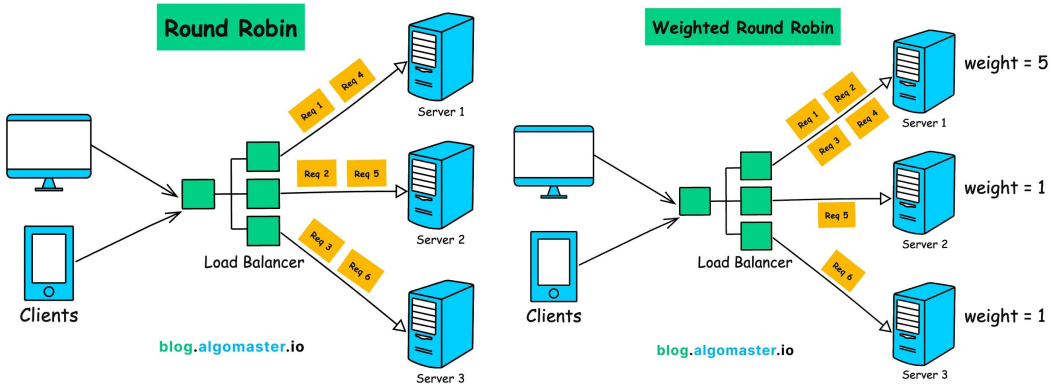
A load balancer is a critical component in distributed systems that acts as a traffic director, sitting between clients and servers. Its primary job is to distribute incoming network requests across multiple backend servers to ensure no single server becomes overwhelmed.



Load Balancing Algorithms:

Round Robin (RR) – equal distribution.

Weighted Round Robin (WRR) – accounts for node capacity.

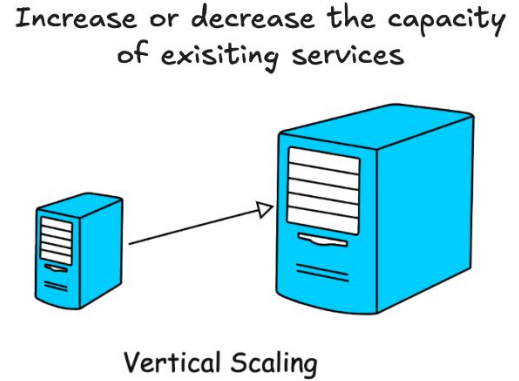


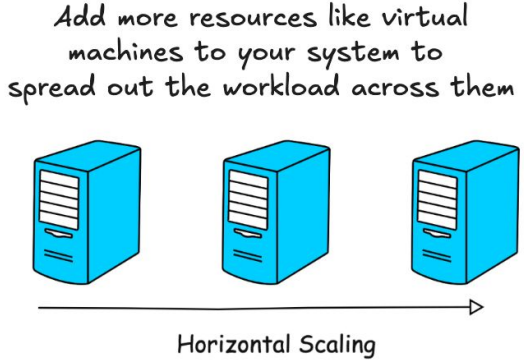
Part 1 — Topics Enjoyed Learning

Vertical vs Horizontal scaling

Things to consider to decide between vertical and horizontal scaling:

- **Cost:** Analyze initial hardware costs vs. long-term operational expenses.
- **Workload:** Is your application CPU bound, memory bound, or does it lend itself to distribution?
- **Architectural Complexity:** Can your application code handle distributed workloads?
- **Future Growth:** How much scaling do you realistically anticipate?





Part 1 — Topics Enjoyed Learning

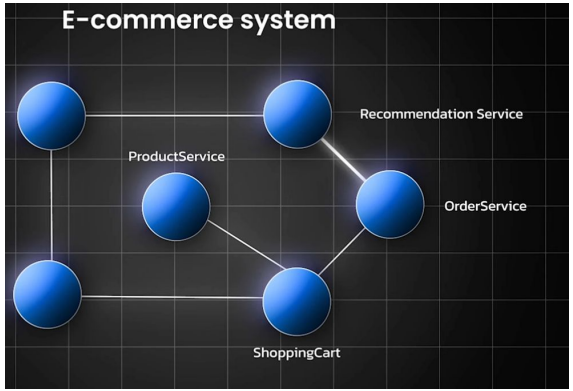
Circuit Breaker Pattern: Building Resilient Microservices

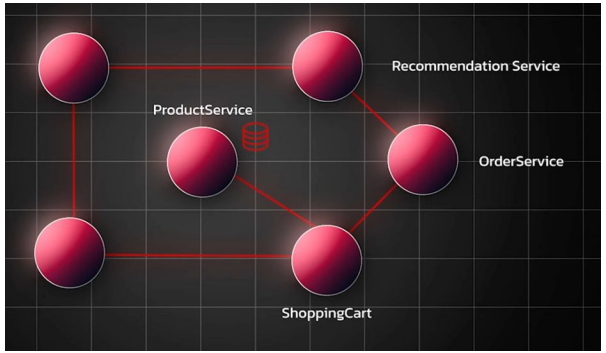
Purpose: Prevent cascading failures by detecting and isolating failing components.

Situation:

For example, a circuit breaker in the shopping cart service could prevent it from repeatedly calling the failing product service, allowing it instead to display a message such as *“Product information temporarily unavailable”* rather than crashing altogether.

The circuit breaker essentially acts as a proxy that monitors the success or failure of operations and decides whether to allow a request to proceed, to immediately return an exception, or to wait for a specified timeout before trying again. It functions as an intelligent gatekeeper, regulating the flow of requests based on the current health of the microservice.



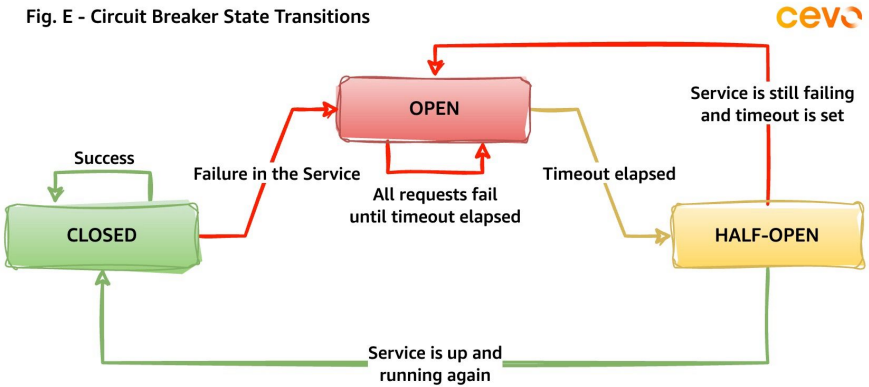


Part 1 — Topics Enjoyed Learning

Circuit Breaker

Circuit Breaker State Transitions

- **Closed:**
  Normal operation — requests pass through while failures and latency are continuously monitored.
- **Open:**
  Triggered when failure rate exceeds a threshold; new requests are immediately rejected to prevent cascading failures.
- **Half-Open:**
  After a timeout, a few test requests are allowed.
  If they **succeed** → **Closed** (service recovered).
  If they **fail** → **Open** (continue protection).



🧩 *Acts as an intelligent gatekeeper that controls traffic based on service health, enabling graceful recovery instead of total failure.*

Part 2 — Crashing & Fixed

Modern Reality: Everything Depends on Everything

- Shopping cart service needs product catalog
- Product service provides pricing and inventory
- **Question: What happens when the product service fails?**

Without Protection: One Failure Brings Down Everything

Scenario: Product service experiences an outage

- Cart service keeps trying to fetch product data
- Each request waits and times out
- Resources get exhausted waiting for failed service
- **Result: Complete system failure**

What We Built

For this experiment, I implemented a microservices architecture on AWS ECS:

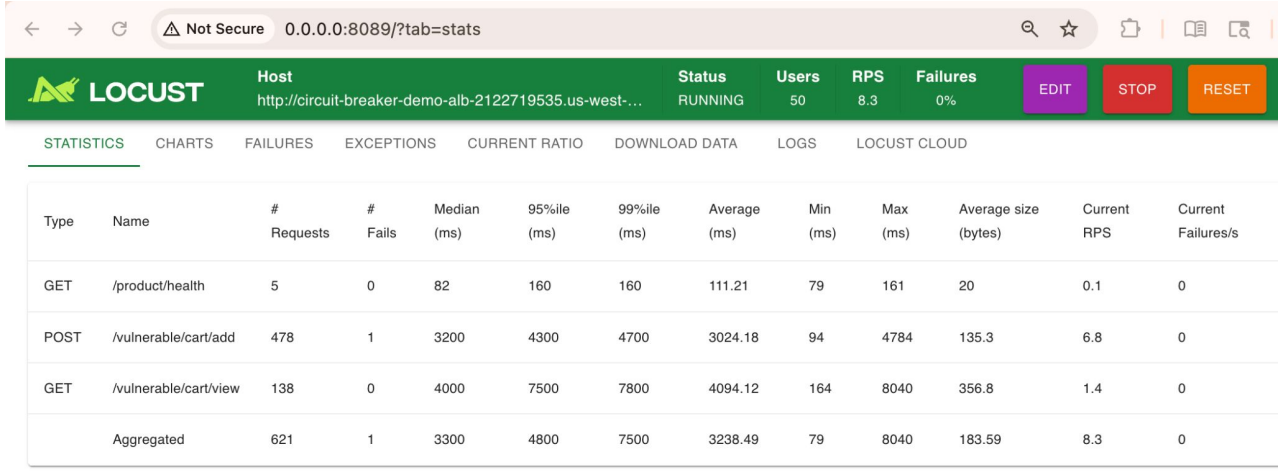
- **Product Service**: Provides product catalog information
- **Cart Service (2 versions)**:
  - Vulnerable version: Direct service calls without protection
  - Fixed version: Implemented with Circuit Breaker pattern
- **Load Balancer**: AWS ALB routing traffic to services

All services were containerized using Docker and deployed on ECS Fargate.

Part 2 — Crashing & Fixed

Baseline Performance (Normal Operation)

- **Failure Rate:** 0%
- **Median Response Time:** 500ms
- **Requests Per Second:** 13.3



Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
GET	/product/health	5	0	82	160	160	111.21	79	161	20	0.1	0
POST	/vulnerable/cart/add	478	1	3200	4300	4700	3024.18	94	4784	135.3	6.8	0
GET	/vulnerable/cart/view	138	0	4000	7500	7800	4094.12	164	8040	356.8	1.4	0
	Aggregated	621	1	3300	4800	7500	3238.49	79	8040	183.59	8.3	0

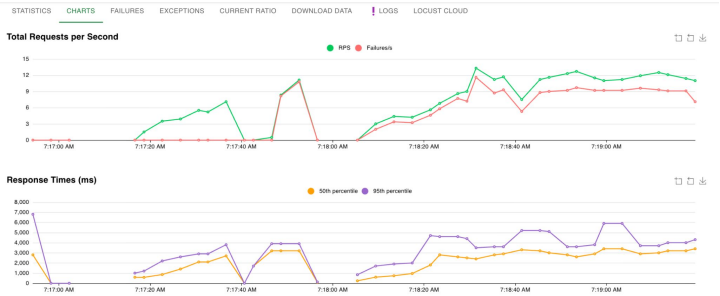
```
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/health
HTTP/1.1 200 OK
Date: Mon, 20 Oct 2025 06:38:25 GMT
Content-Type: application/json
Content-Length: 20
Connection: keep-alive
server: uvicorn

{"status":"healthy"}
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/products
HTTP/1.1 200 OK
Date: Mon, 20 Oct 2025 06:40:46 GMT
Content-Type: application/json
Content-Length: 271
Connection: keep-alive
server: uvicorn

[{"id":"1","name":"Laptop","price":999.99,"stock":10},{"id":"2","name":"Mouse","price":29.99,"stock":100},{"id":"3","name":"Keyboard","price":79.99,"stock":50},{"id":"4","name":"Monitor","price":299.99,"stock":20},{"id":"5","name":"Headphones","price":149.99,"stock":30}]
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/products/1
HTTP/1.1 200 OK
Date: Mon, 20 Oct 2025 06:40:53 GMT
Content-Type: application/json
Content-Length: 52
Connection: keep-alive
server: uvicorn

{"id":"1","name":"Laptop","price":999.99,"stock":10}
(base) ronghuang@Reginas-macbook CS6650 %
```

```
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/vulnerable/health
HTTP/1.1 200 OK
Date: Mon, 20 Oct 2025 07:07:56 GMT
Content-Type: application/json
Content-Length: 40
Connection: keep-alive
server: uvicorn

{"status":"healthy","mode":"vulnerable"}
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/fixed/health
HTTP/1.1 200 OK
Date: Mon, 20 Oct 2025 07:08:01 GMT
Content-Type: application/json
Content-Length: 72
Connection: keep-alive
server: uvicorn

{"status":"healthy","mode":"protected","circuit_breaker_state":"CLOSED"}
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/vulnerable/cart
HTTP/1.1 404 Not Found
Date: Mon, 20 Oct 2025 07:08:08 GMT
Content-Type: application/json
Content-Length: 22
Connection: keep-alive
server: uvicorn

{"detail":"Not Found"}
(base) ronghuang@Reginas-macbook CS6650 % curl -i http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/fixed/cart
HTTP/1.1 404 Not Found
Date: Mon, 20 Oct 2025 07:08:16 GMT
Content-Type: application/json
Content-Length: 22
Connection: keep-alive
server: uvicorn

{"detail":"Not Found"}
(base) ronghuang@Reginas-macbook CS6650 %
```

Part 2 — Crashing & Fixed

Crash: After Product Service Failure

- **Failure Rate:** 80% overall (506/506 for cart/add = 100% failure)
- **Response Time:** 2800ms median, up to 5900ms (99th percentile)
- **System Impact:** Complete service degradation - cart operations completely failed



Not Secure 0.0.0.0:8089/?tab=stats

LOCUST | Host: http://circuit-breaker-demo-alb-2122719535.us-west-... | Status: RUNNING | Users: 50 | RPS: 12.5 | Failures: 80% | EDIT | STOP | RESET

STATISTICS | CHARTS | FAILURES | EXCEPTIONS | CURRENT RATIO | DOWNLOAD DATA | LOGS | LOCUST CLOUD

Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
GET	/product/health	4	4	78	160	160	117.37	75	159	68	0.1	0.1
POST	/vulnerable/cart/add	506	506	3000	5300	5900	2890.73	93	5981	83.87	9.1	9.1
GET	/vulnerable/cart/view	167	30	1200	3600	5700	1499.03	77	5694	48.6	3.3	0.1
	Aggregated	677	540	2800	5200	5900	2531.04	75	5981	75.08	12.5	9.3

Part 2 — Crashing & Fixed

Fix: Enter the Circuit Breaker Pattern

Failure Detection and Response

```
def __init__(
    self,
    failure_threshold: int = 5, # Open after 5 failures
    recovery_timeout: int = 60, # Try recovery after 60 seconds
    expected_exception: Type[Exception] = Exception,
    success_threshold: int = 2 # Need 2 successes to close
):
```

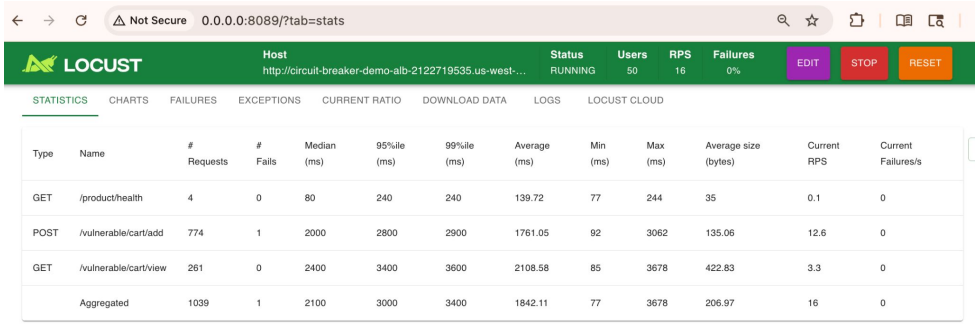
Smart Fallback Mechanisms:

- Use cached product data when available
- Allow cart operations with degraded information
- Maintain business continuity even during outages

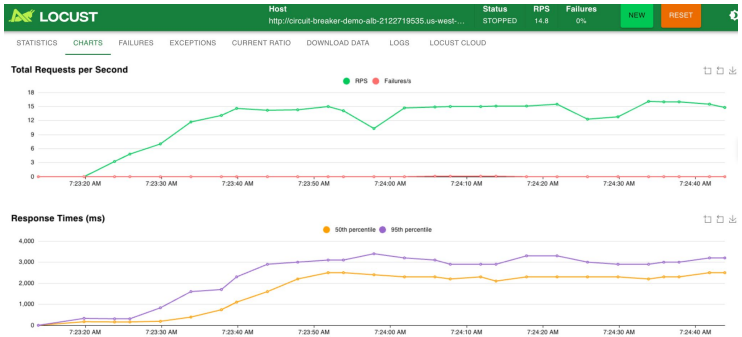
Part 2 — Crashing & Fixed

Fix: Enter the Circuit Breaker Pattern

use fix mode, no failure



Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
GET	/product/health	4	0	80	240	240	139.72	77	244	35	0.1	0
POST	/vulnerable/cart/add	774	1	2000	2800	2900	1761.05	92	3062	135.06	12.6	0
GET	/vulnerable/cart/view	261	0	2400	3400	3600	2108.58	85	3678	422.83	3.3	0
	Aggregated	1039	1	2100	3000	3400	1842.11	77	3678	206.97	16	0




```
sion(s)
[2025-10-20 08:33:02,927] Reginas-macbook/INFO/loc
ustfile: User user_864 started - Testing fixed ver
sion(s)
[2025-10-20 08:33:05,663] Reginas-macbook/INFO/loc
ustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:33:05,777] Reginas-macbook/INFO/loc
ustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:33:16,570] Reginas-macbook/INFO/loc
ustfile: Circuit Breaker State: CLOSED
```

Part 2 — Crashing & Fixed

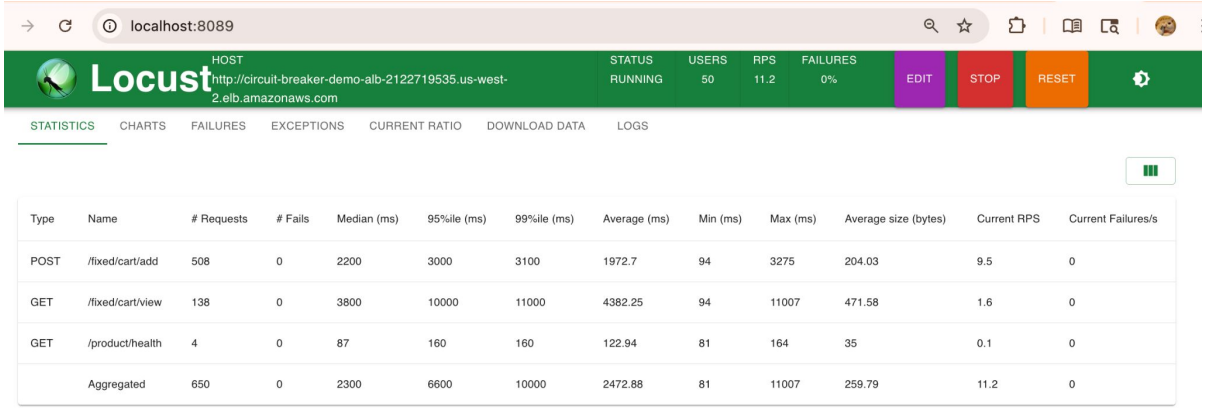
Fix: Enter the Circuit Breaker Pattern

Trigger failure

```
(base) ronghuang@Reginas-macbook midterm % curl -X POST http://circuit-breaker-demo-alb-2122719535.us-west-2.elb.amazonaws.com/fail/on
{"message":"Failure enabled"}%
(base) ronghuang@Reginas-macbook midterm %
```

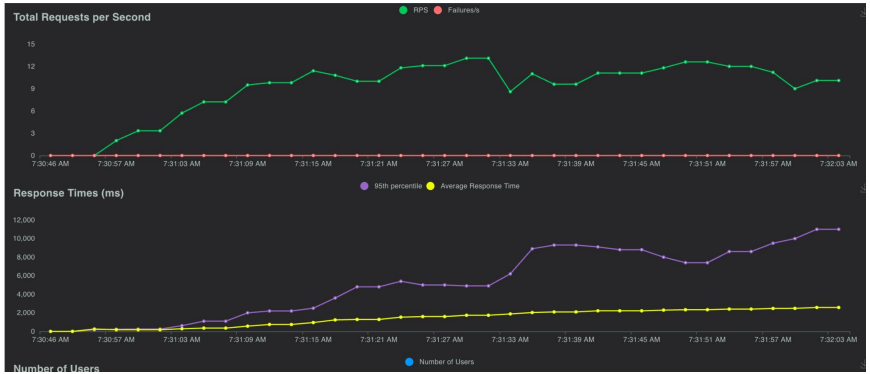
circuit breaker state

```
[2025-10-20 08:38:57,846] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:38:58,119] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:38:58,568] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:38:59,453] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:39:00,668] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:39:01,053] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
```



Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
POST	/fixed/cart/add	508	0	2200	3000	3100	1972.7	94	3275	204.03	9.5	0
GET	/fixed/cart/view	138	0	3800	10000	11000	4382.25	94	11007	471.58	1.6	0
GET	/product/health	4	0	87	160	160	122.94	81	164	35	0.1	0
	Aggregated	650	0	2300	6600	10000	2472.88	81	11007	259.79	11.2	0

Part 2 — Crashing & Fixed



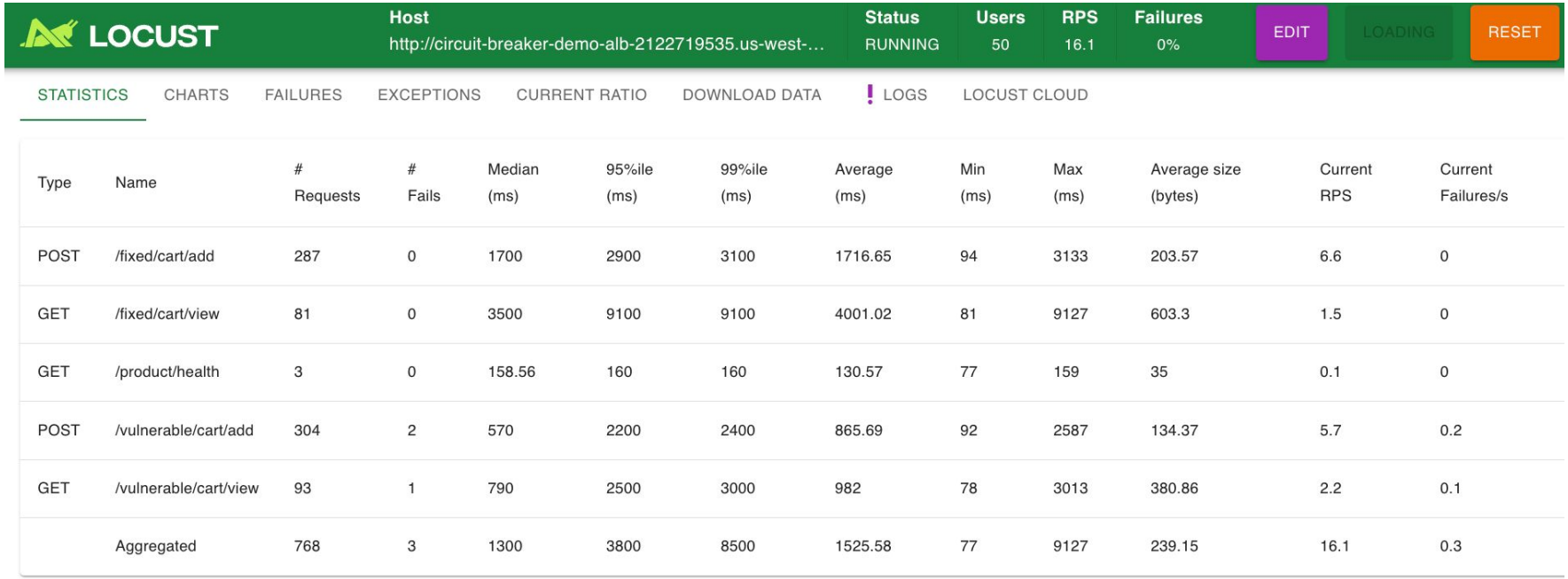

```
[2025-10-20 08:38:58,119] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:38:58,568] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:38:59,453] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:39:00,668] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:39:01,053] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:39:29,959] Reginas-macbook/ERROR/locustfile: ⚠️PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 08:39:42,482] Reginas-macbook/ERROR/locustfile: ⚠️PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 08:40:46,277] Reginas-macbook/INFO/locust.runners: Ramping to 50 users at a rate of
2.00 per second
[2025-10-20 08:40:46,277] Reginas-macbook/INFO/locust.runners: All users spawned: {"AdminUser":
2, "EcommerceUser": 48} (50 total users)
[2025-10-20 08:40:51,513] Reginas-macbook/INFO/locustfile: ✅ Product service has recovered
[2025-10-20 08:40:57,475] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
```

```
[2025-10-20 08:48:14,127] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:48:14,314] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:48:14,594] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:48:14,886] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:48:15,686] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 08:48:19,918] Reginas-macbook/ERROR/locustfile: ⚠️ PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 08:48:33,873] Reginas-macbook/ERROR/locustfile: ⚠️ PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 08:50:00,769] Reginas-macbook/INFO/locustfile: ✅ Product service has recovered
[2025-10-20 08:50:11,125] Reginas-macbook/INFO/locustfile: ✅ Product service has recovered
[2025-10-20 08:50:11,953] Reginas-macbook/INFO/locustfile: Circuit Breaker State: HALF_OPEN
[2025-10-20 08:50:13,277] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:50:13,278] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:50:13,278] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:50:13,279] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 08:50:13,467] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
```

Part 2 — Crashing & Fixed

Compare: run at the same time

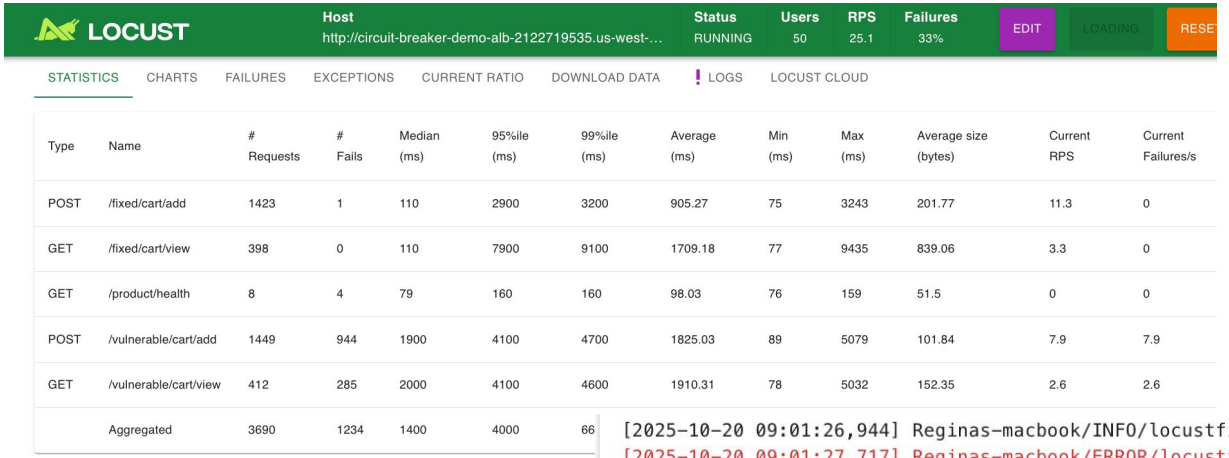
baseline: no failure



Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
POST	/fixed/cart/add	287	0	1700	2900	3100	1716.65	94	3133	203.57	6.6	0
GET	/fixed/cart/view	81	0	3500	9100	9100	4001.02	81	9127	603.3	1.5	0
GET	/product/health	3	0	158.56	160	160	130.57	77	159	35	0.1	0
POST	/vulnerable/cart/add	304	2	570	2200	2400	865.69	92	2587	134.37	5.7	0.2
GET	/vulnerable/cart/view	93	1	790	2500	3000	982	78	3013	380.86	2.2	0.1
	Aggregated	768	3	1300	3800	8500	1525.58	77	9127	239.15	16.1	0.3

Part 2 — Crashing & Fixed

Compare Trigger failure



Type	Name	# Requests	# Fails	Median (ms)	95%ile (ms)	99%ile (ms)	Average (ms)	Min (ms)	Max (ms)	Average size (bytes)	Current RPS	Current Failures/s
POST	/fixed/cart/add	1423	1	110	2900	3200	905.27	75	3243	201.77	11.3	0
GET	/fixed/cart/view	398	0	110	7900	9100	1709.18	77	9435	839.06	3.3	0
GET	/product/health	8	4	79	160	160	98.03	76	159	51.5	0	0
POST	/vulnerable/cart/add	1449	944	1900	4100	4700	1825.03	89	5079	101.84	7.9	7.9
GET	/vulnerable/cart/view	412	285	2000	4100	4600	1910.31	78	5032	152.35	2.6	2.6
	Aggregated	3690	1234	1400	4000	66						

```
[2025-10-20 09:01:26,944] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 09:01:27,717] Reginas-macbook/ERROR/locustfile: ⚠️ PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 09:01:30,548] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 09:01:30,554] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 09:01:34,034] Reginas-macbook/INFO/locustfile: Circuit Breaker State: OPEN
[2025-10-20 09:01:50,256] Reginas-macbook/ERROR/locustfile: ⚠️ PRODUCT SERVICE IS UNHEALTHY!
[2025-10-20 09:03:22,542] Reginas-macbook/INFO/locustfile: ✅ Product service has recovered
[2025-10-20 09:03:35,061] Reginas-macbook/INFO/locustfile: Circuit Breaker State: HALF_OPEN
[2025-10-20 09:03:35,065] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:35,181] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:35,260] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:35,260] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:36,876] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:36,876] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:36,877] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
[2025-10-20 09:03:36,878] Reginas-macbook/INFO/locustfile: Circuit Breaker State: CLOSED
```

Part 2 — Crashing & Fixed

The Power of Protection

Metric	Vulnerable Version	Protected Version	Improvement
Add to Cart Failure Rate	65% (944/1449)	0.07% (1/1423)	**99.9% reduction**
View Cart Failure Rate	69% (285/412)	0% (0/398)	**100% elimination**
Response Time (median)	1900-2000ms	110ms	**17-18x faster**
Throughput	10.5 RPS	14.6 RPS	**39% higher**

Part 2 — Crashing & Fixed

Conclusion

The Problem: One service failure caused 95% system failure

The Solution: Circuit Breaker pattern with intelligent fallbacks

The Result: System maintains 99.93% availability even during failures

> "In distributed systems, failure isn't a possibility - it's a certainty. The Circuit Breaker pattern transforms inevitable failures from disasters into minor inconveniences."

Thank you !