EPFL

Dependability through Redundancy

Prof. George Candea
School of Computer & Communication Sciences

How to achieve dependability?

- Use modularity ...
- ... and REDUNDANCY for ...
  - *fault tolerance*
  - *high reliability*
  - *high availability*

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Redundancy = duplication with the purpose of increasing dependability

Fault tolerance

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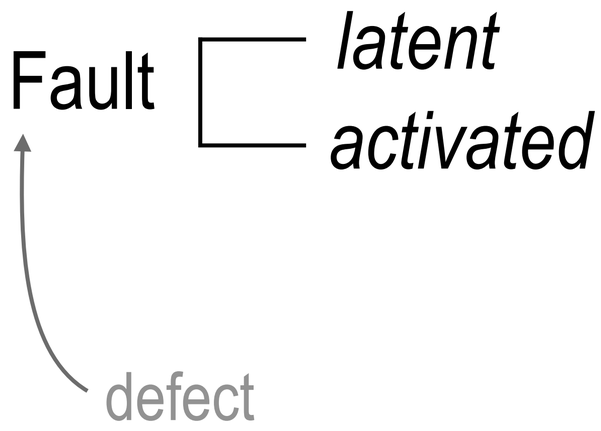
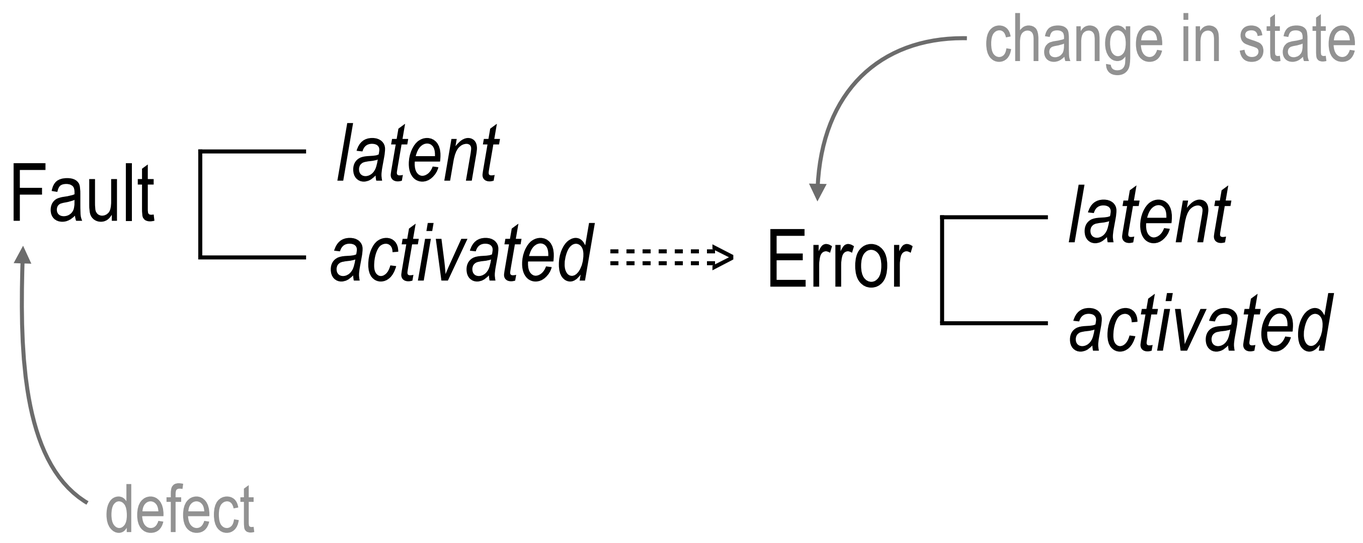


Fault tolerance



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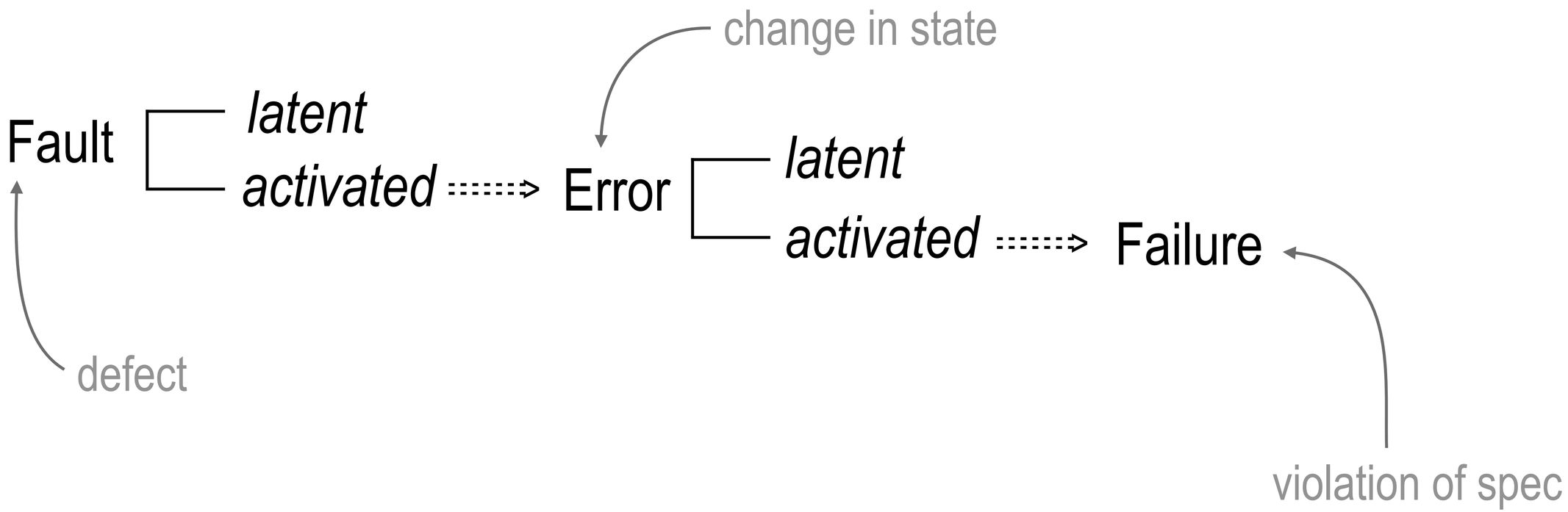
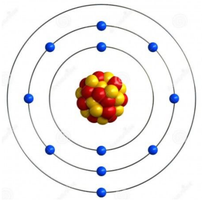
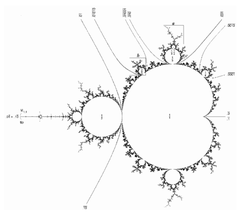


Types of software faults / defects



$$\Delta\chi\Delta\rho \geq \frac{\hbar}{2}$$



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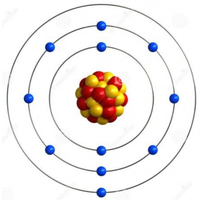

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  - *clear + easy to reproduce => easy to fix*
- Heisenbug
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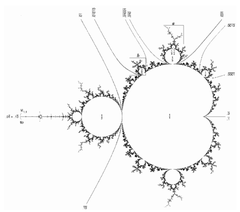

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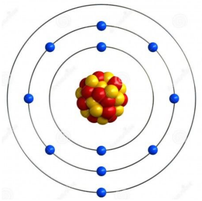

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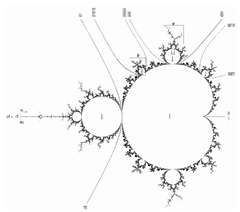
- Schrödingbug
  - *starts causing failure once you realize it should*



- Mandelbug
  - *complex, obscure, chaotic, seemingly non-deterministic*

Using redundancy to tolerate faults

- "tolerate" faults = cope with errors or the resulting failures
  - *the actual goal is to tolerate the consequences of faults*
- Using redundancy to cope with errors
  - *forward error correction*
  - *redundant copies/replicas (=coarse-grained ECC)*
  - *...*
- Using redundancy to cope with failures
  - *server/service failover*
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Data/information redundancy

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Data/information redundancy

Geographic redundancy

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Processing redundancy

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Data/information redundancy

Geographic redundancy

Processing redundancy

Space

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Data/information redundancy

Geographic redundancy

Processing redundancy
- Space
- Time

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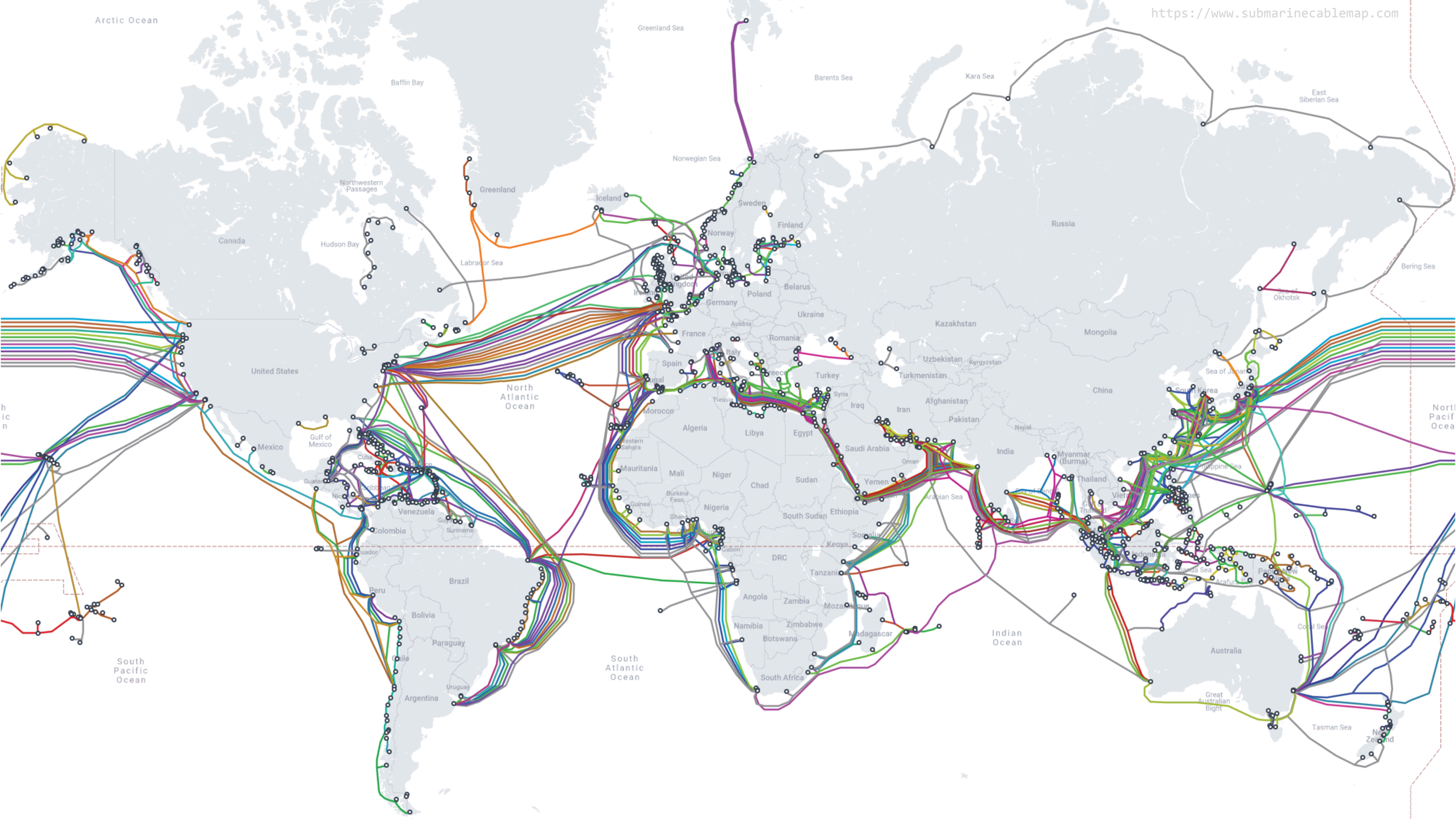
Functional redundancy


https://www.submarinecablemap.com
Arctic Ocean
Greenland Sea
Barents Sea
Kara Sea
East Siberian Sea
Baffin Bay
Norwegian Sea
Northwestern Passages
Greenland
Iceland
Sweden
Finland
Russia
Canada
Hudson Bay
Labrador Sea
Norway
Bering Sea
Sea of Okhotsk
Belarus
Poland
Germany
Ukraine
Kazakhstan
Mongolia
France
Austria
Romania
Italy
Spain
Uzbekistan
Kyrgyzstan
Turkmenistan
Turkey
China
United States
North Atlantic Ocean
Syria
Iraq
Iran
Afghanistan
Pakistan
Nepal
India
Morocco
Algeria
Tunisia
Libya
Egypt
Saudi Arabia
Oman
Myanmar (Burma)
Thailand
Mexico
Gulf of Mexico
Mauritania
Mali
Niger
Chad
Sudan
Yemen
Arabian Sea
Philippine Sea
Burkina Faso
Guinea
Nigeria
South Sudan
Ethiopia
Venezuela
Colombia
Kenya
Somalia
DRC
Tanzania
Brazil
Peru
Angola
Zambia
Mozambique
Bolivia
Namibia
Zimbabwe
Madagascar
Botswana
Paraguay
Chile
South Africa
Indian Ocean
Australia
Coral Sea
Uruguay
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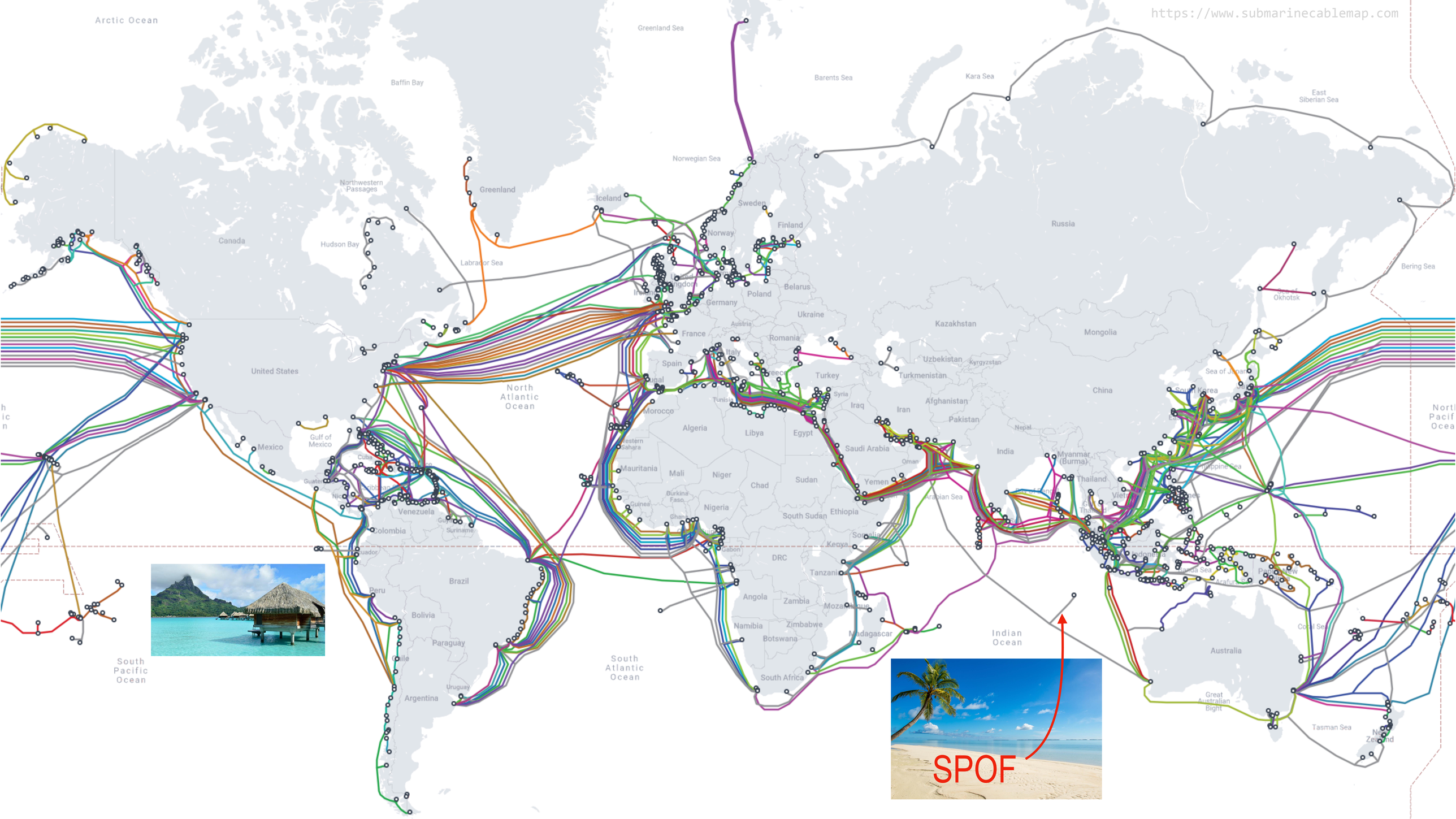
Great Australian Bight
Tasman Sea
New Zealand
South Pacific Ocean
South Atlantic Ocean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Turkmenistan
Turkey
China
North Atlantic Ocean
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Algeria
Libya
Egypt
Syria
Iraq
Iran
Afghanistan
Pakistan
Nepal
India
Saudi Arabia
Oman
Yemen
Mexico
Gulf of Mexico
Mauritania
Mali
Niger
Chad
Sudan
Myanmar (Burma)
Thailand
Philippine Sea
Arabian Sea
Nigeria
South Sudan
Ethiopia
Kenya
Somalia
Venezuela
Colombia
DRC
Tanzania
Brazil
Peru
Angola
Zambia
Mozambique
Namibia
Zimbabwe
Botswana
Madagascar
South Africa
Bolivia
Paraguay
Chile
Uruguay
Argentina
South Pacific Ocean
South Atlantic Ocean
Indian Ocean
Australia
Great Australian Bight
Tasman Sea
New Zealand
SPOF

Fault model

- Specification of what could go wrong and what cannot go wrong
  - *Used to predict consequences of failures*
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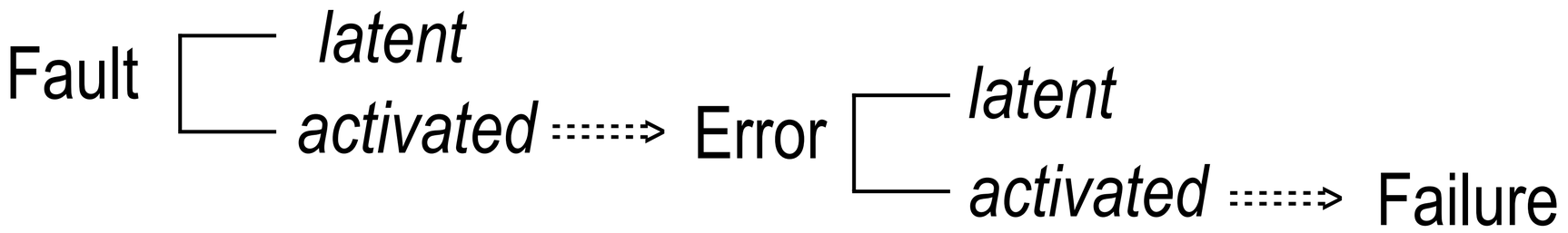
- Example: N-version programming
  - *use redundancy to tolerate software faults*

Recap: Fault tolerance



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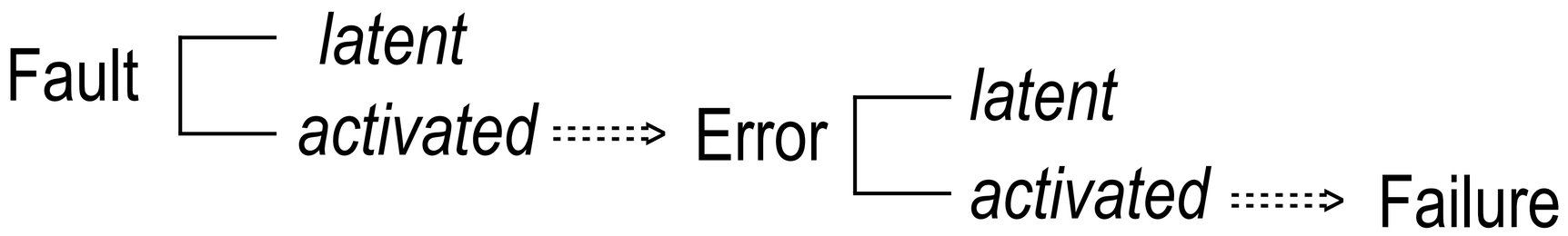

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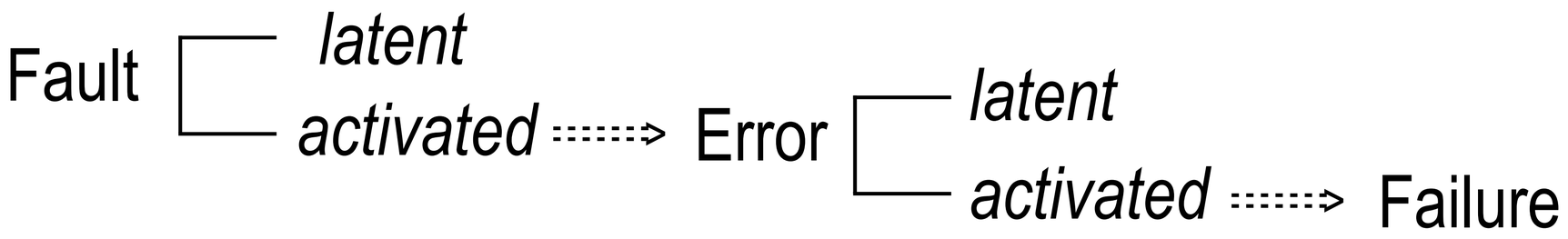

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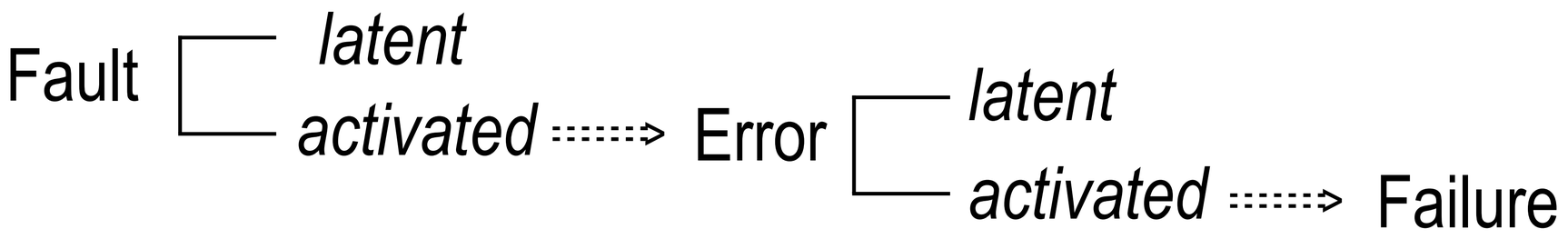

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  - *Bohrbug, Heisenbug, …*
- Redundancy helps tolerate errors and failures
  - *Data redundancy, processing redundancy, ...*
- Fault model = assumptions about what can vs. cannot go wrong

Safety-critical systems

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  - *SCADA, aviation, space, automotive, healthcare, …*
- Fail-safe = failure does not have "bad" consequences
  - *safety-critical ⇏ fail-safe*

Dependable systems

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- Maintainability = ability to undergo repairs and modifications

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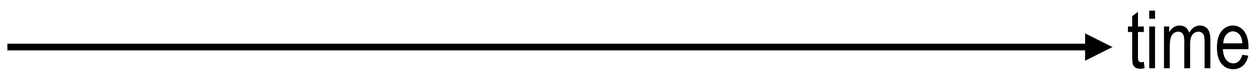

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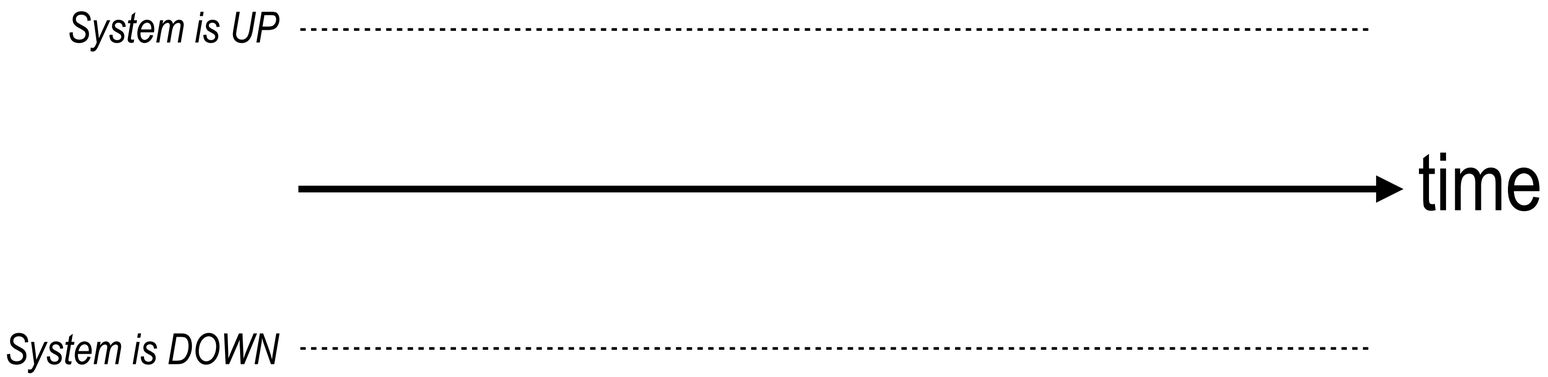

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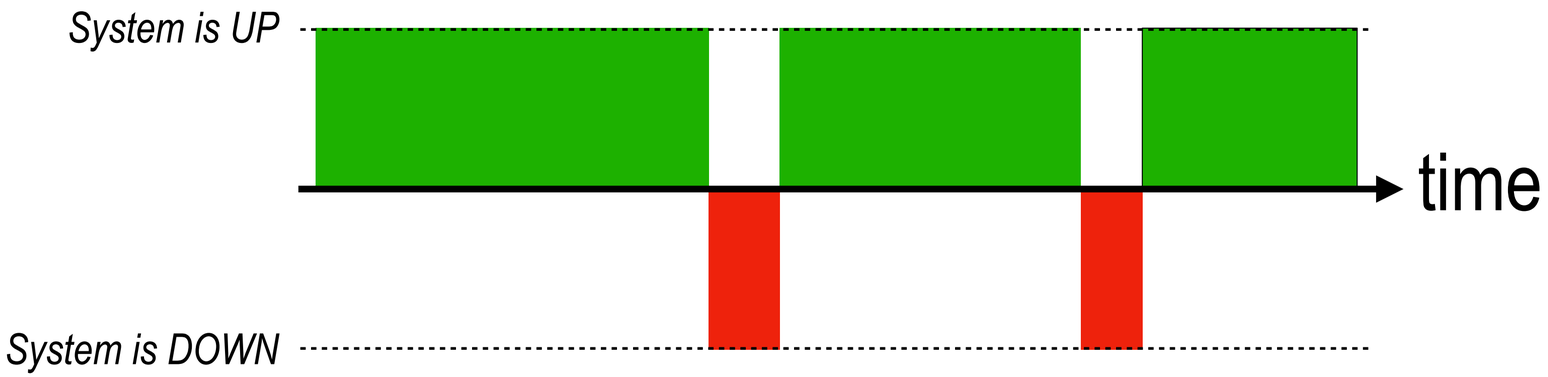

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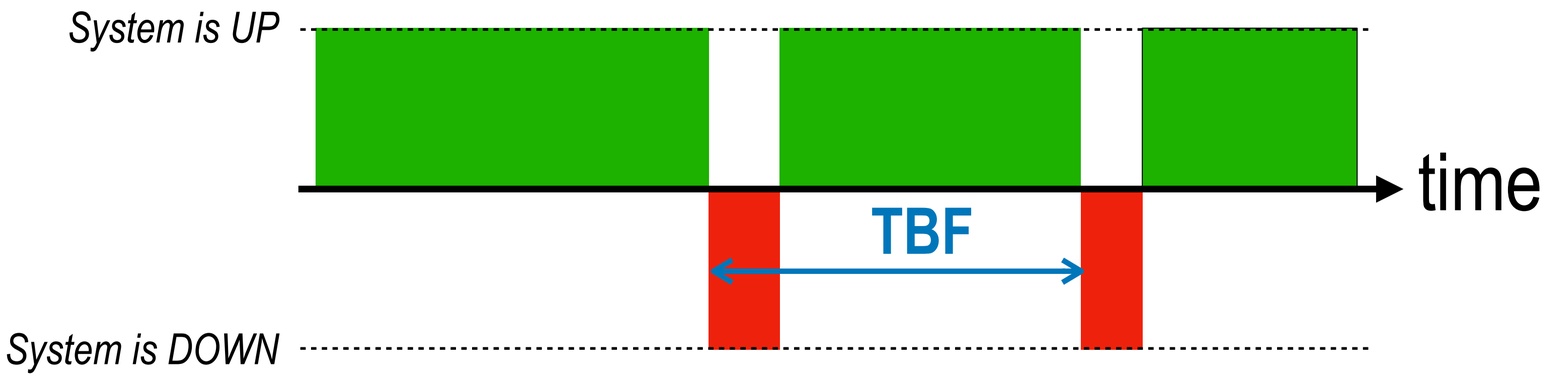

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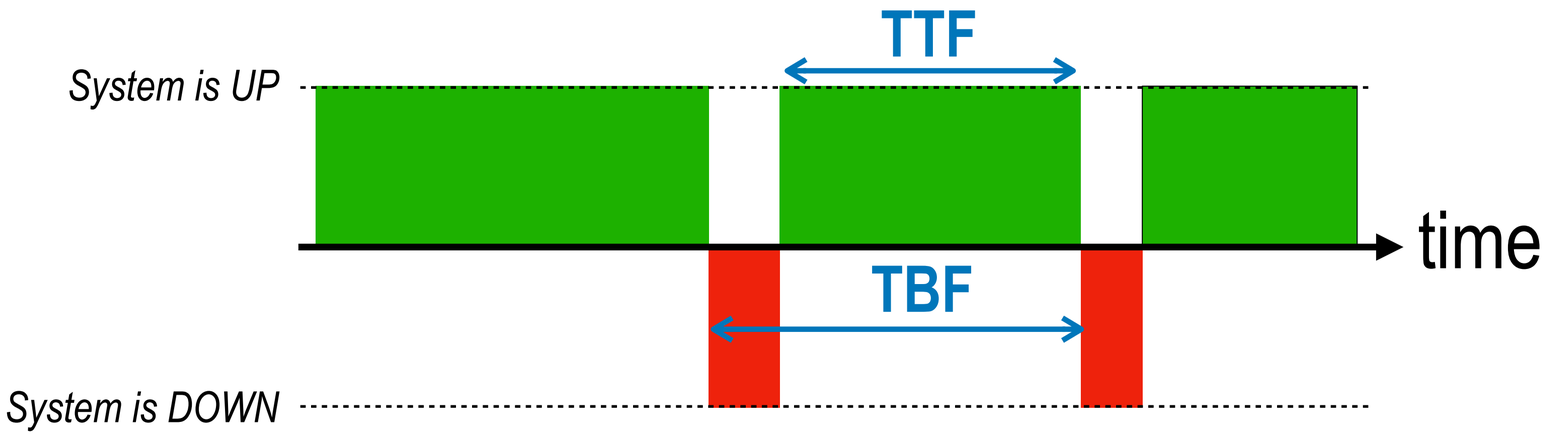

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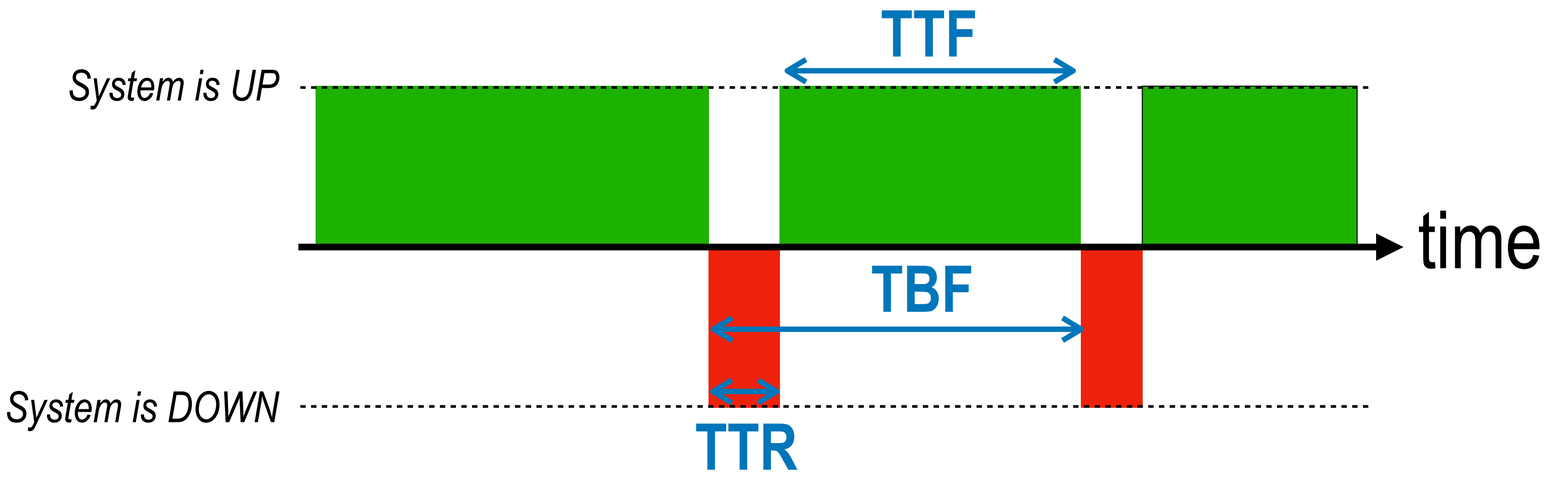

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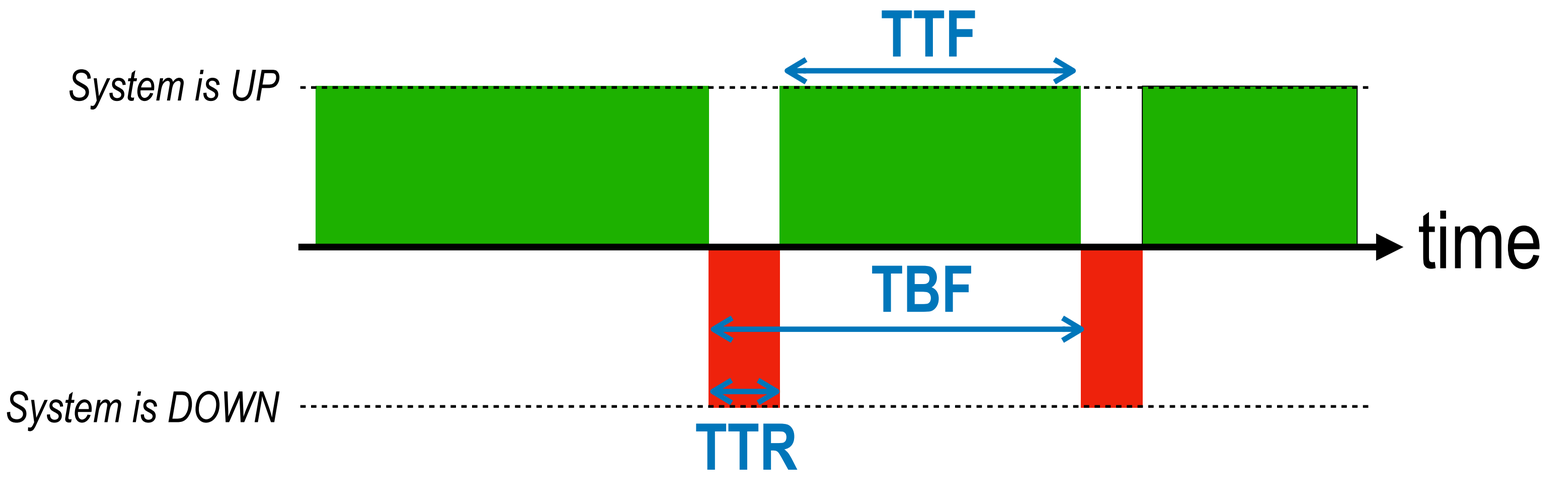

MTBF = MTTF + MTTR

Measuring reliability

- In general MTBF or MTTF (MTBF = MTTF + MTTR)
  - *Specifics: Example from SSD spec sheet: P/E cycles, TBW, GB/day, DWPD, MTBF ...*
- Example: Samsung SSD 850 Pro SATA
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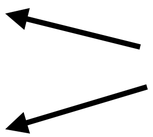

Why different???

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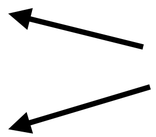

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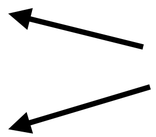
    - 2.5K SSDs => you'd experience 1 failure every ~100 days (2M / 8 / 2500)



Why different???

Recap: Reliability

- Dependability = Reliability + Availability + Safety + …
- Safety-critical vs. reliable
- MTBF = MTTF + MTTR

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Level of Availability	Percent of Uptime	Downtime per Year	Downtime per Day
1 Nine	90%	36.5 days	2.4 hrs.
2 Nines	99%	3.65 days	14 min.
3 Nines	99.9%	8.76 hrs.	86 sec.
4 Nines	99.99%	52.6 min.	8.6 sec.
5 Nines	99.999%	5.25 min.	.86 sec.
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5 Nines	99.999%	5.25 min.	.86 sec.
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↑×10

↓÷10

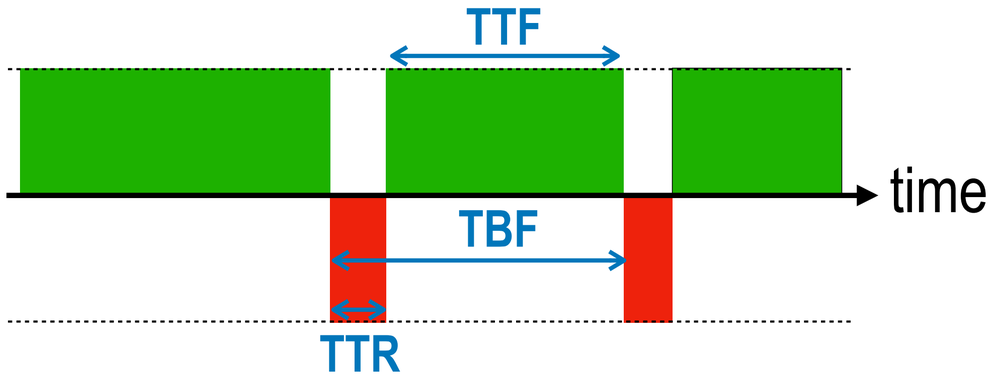
Availability vs. Reliability

- Continuity of service does not matter (unlike reliability)
  - *In theory: uptime is too strict a measure of availability*
  - *In practice: what's the difference?*
- Uptime => availability but Availability ⇏ uptime
- Examples of …
  - *Highly available systems with poor reliability (and how is redundancy used)*

    …
  - *Highly reliable systems with poor availability (and how is redundancy used)*

    …

System availability



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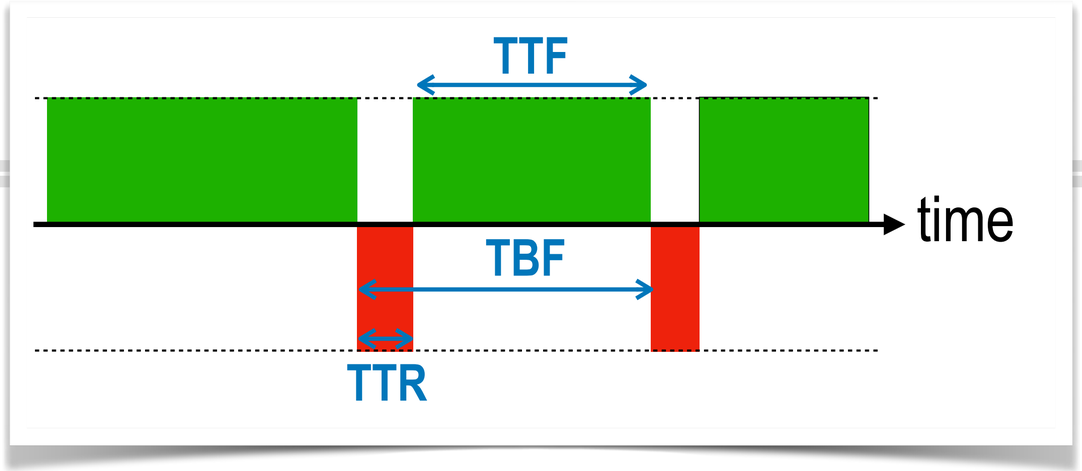

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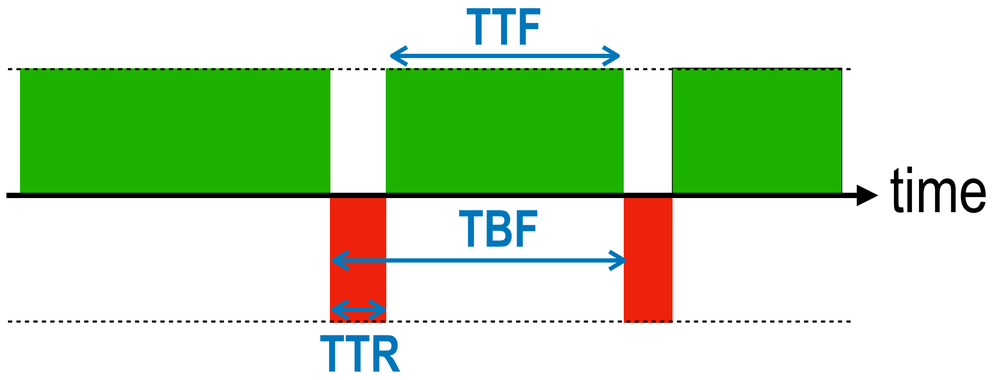

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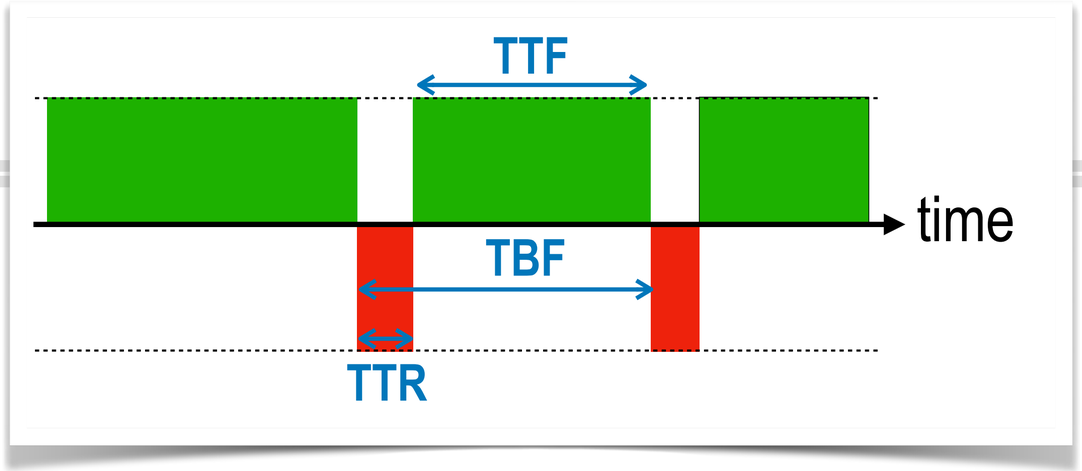

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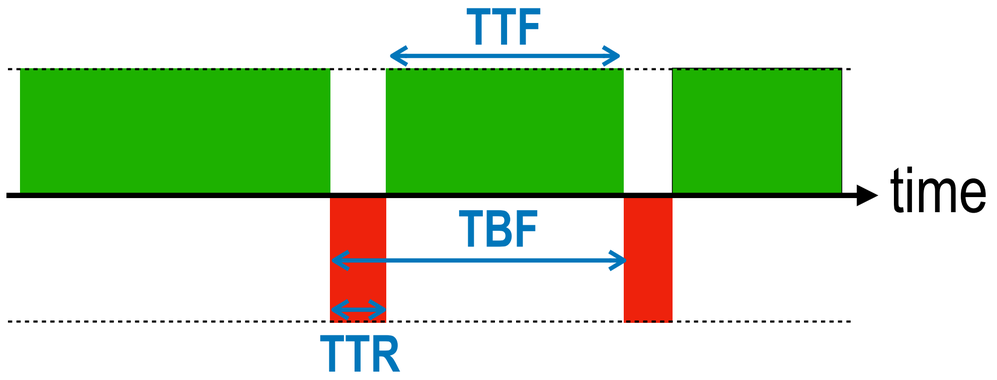

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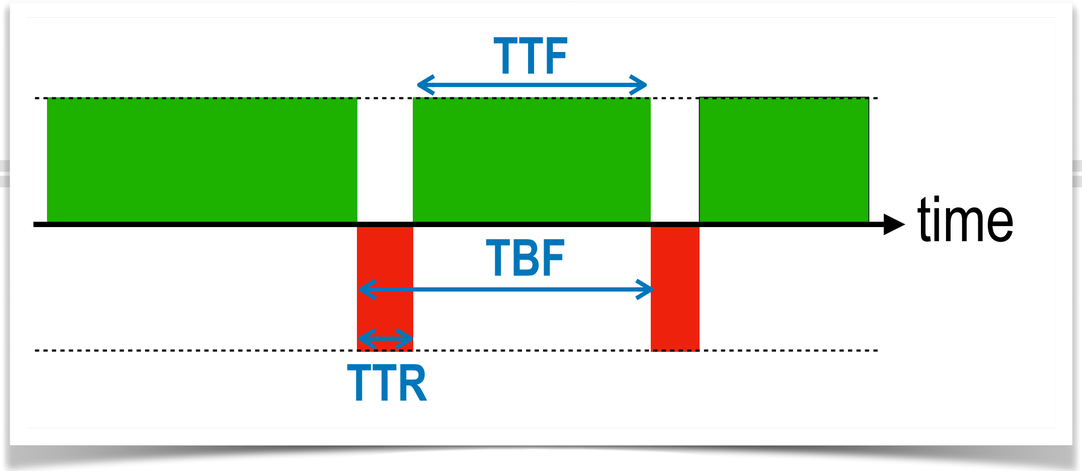

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- Increase availability by
  - *increasing MTTF (higher reliability)*
  - *reducing MTTR (faster recovery)*

Failure modes

Failure modes

- Definition:

  When a system fails, how does that failure appear at the interface of a component?

- Four kinds
  - *fail-stop*
  - *fail-fast*
  - *fail-safe*
  - *fail-soft*

Failure mode 1: Fail-stop

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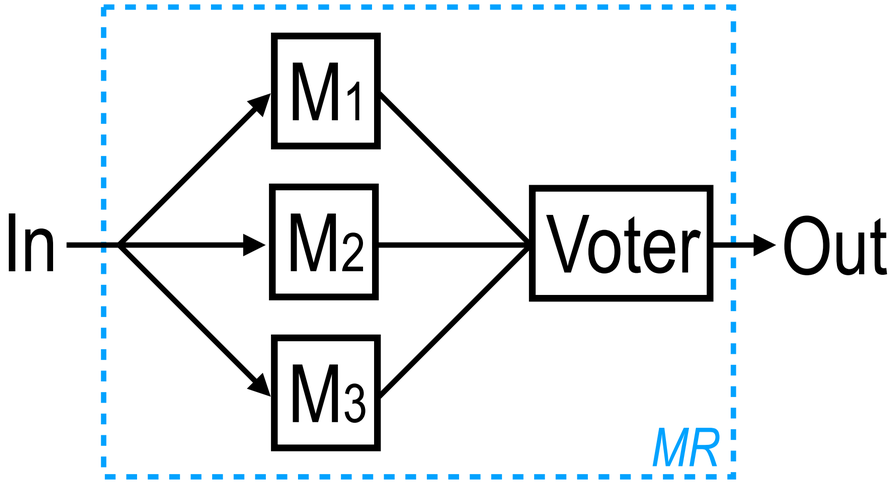

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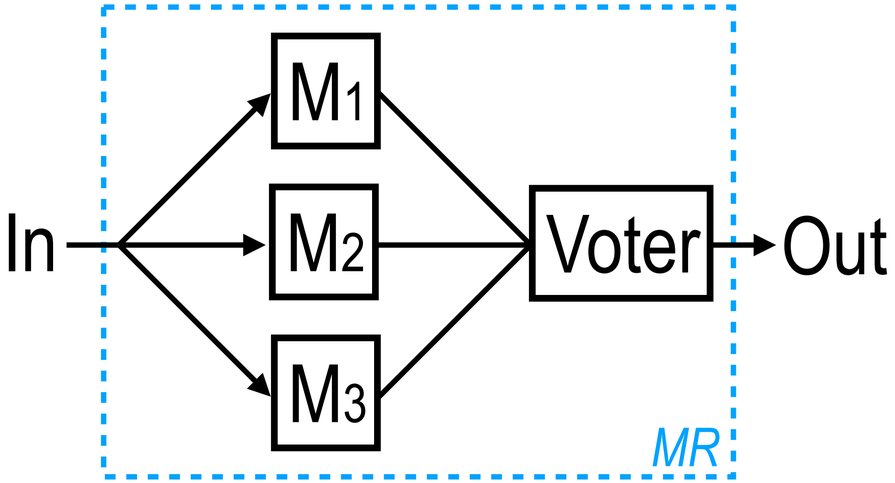

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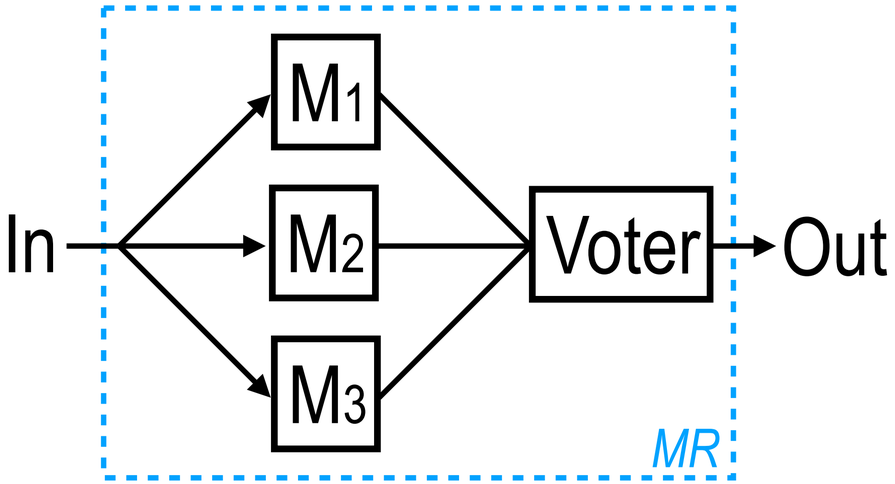

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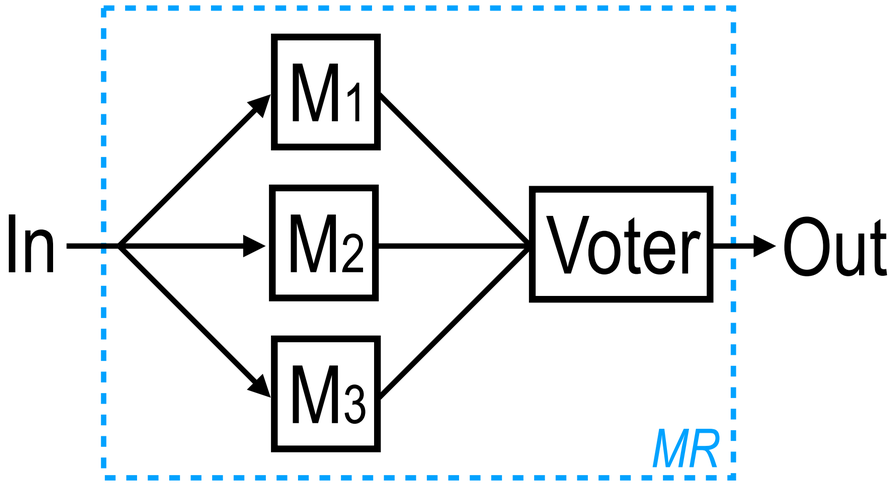

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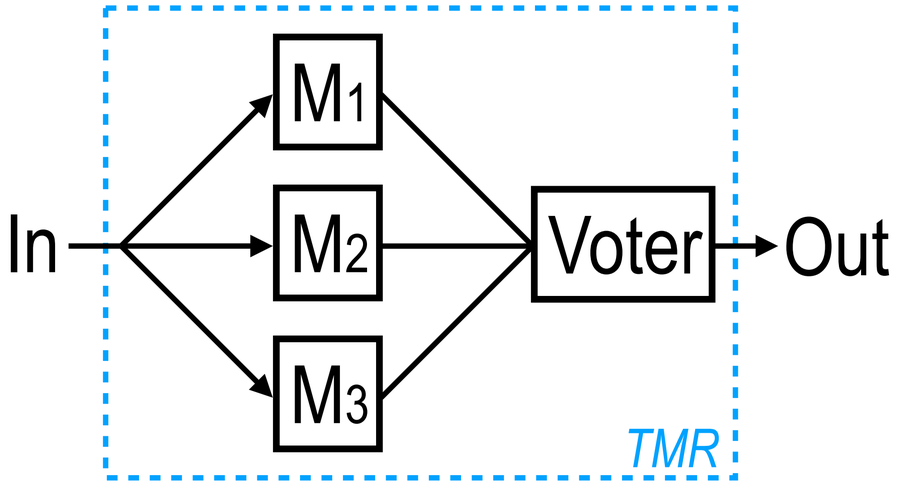

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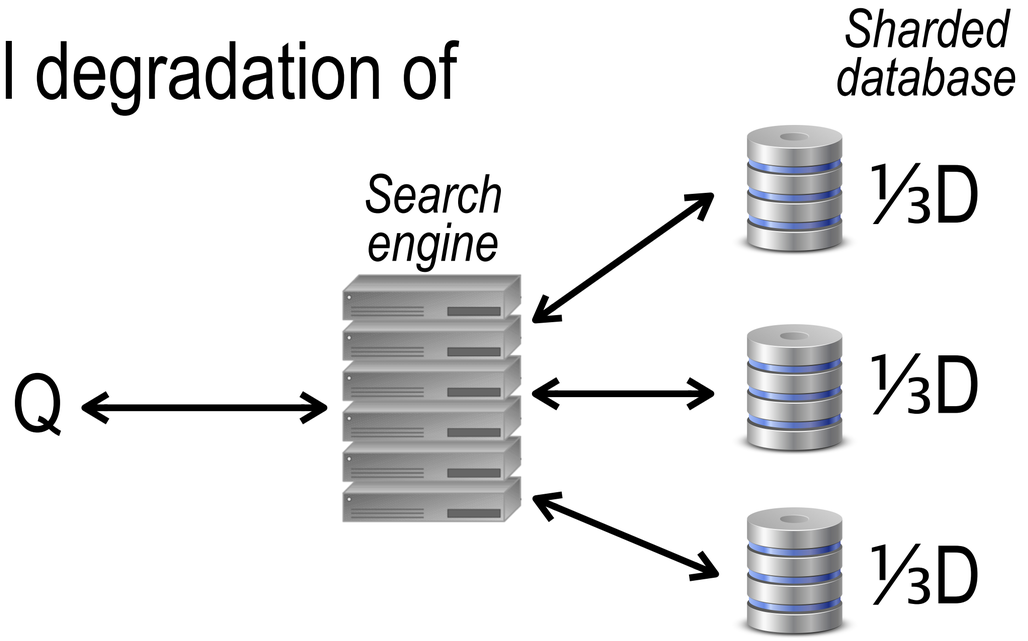

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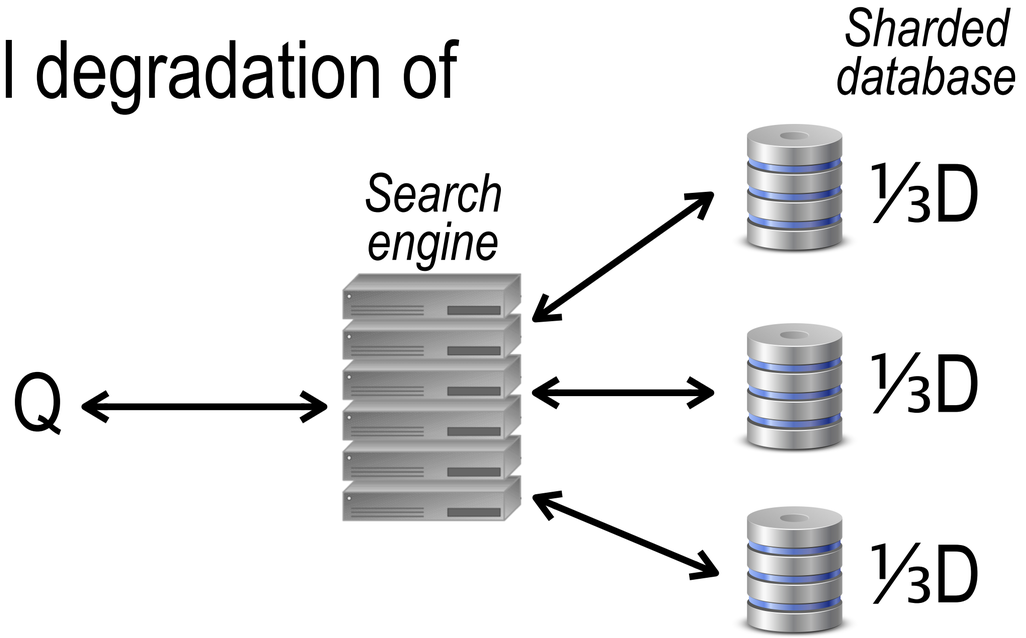

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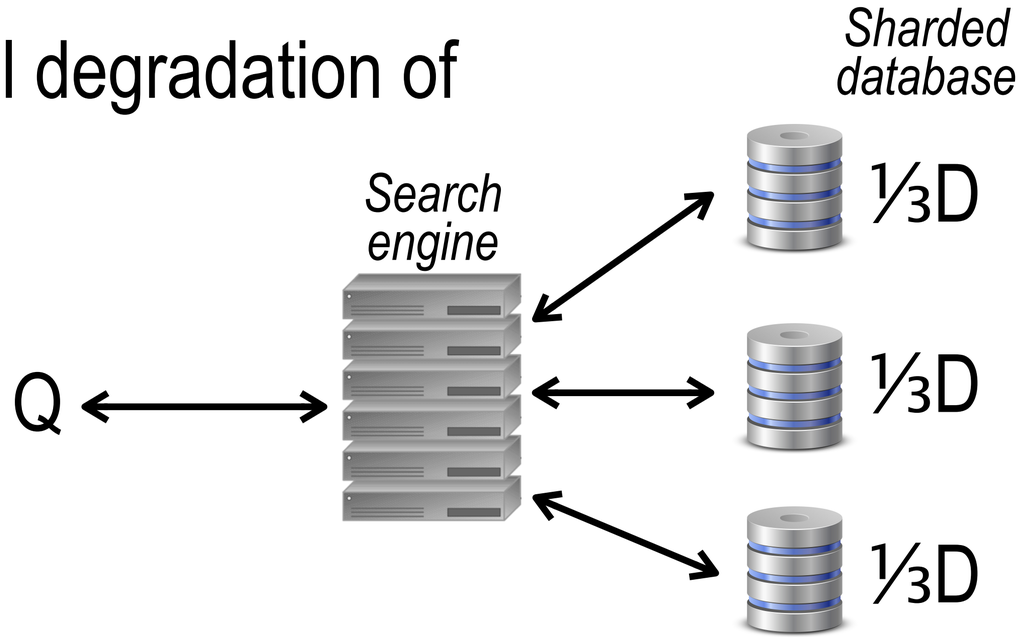

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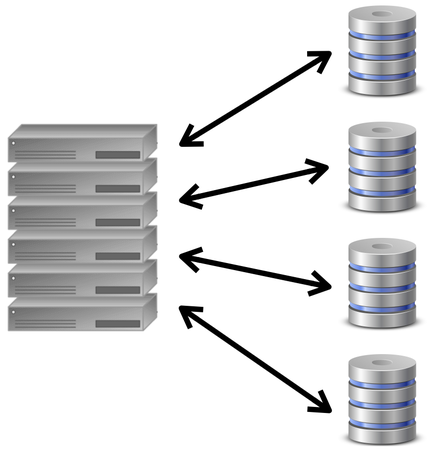

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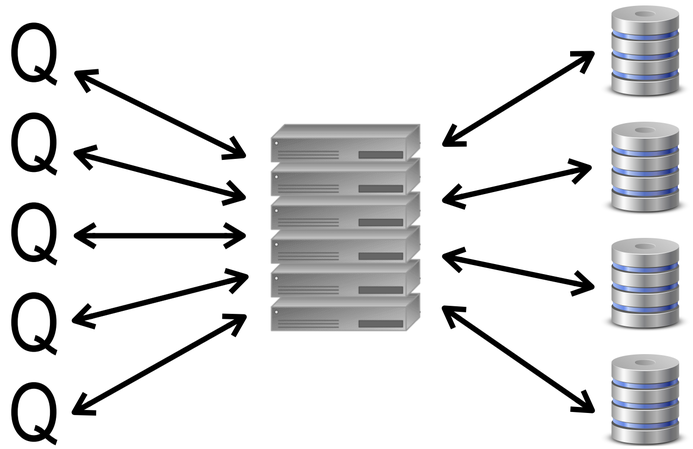

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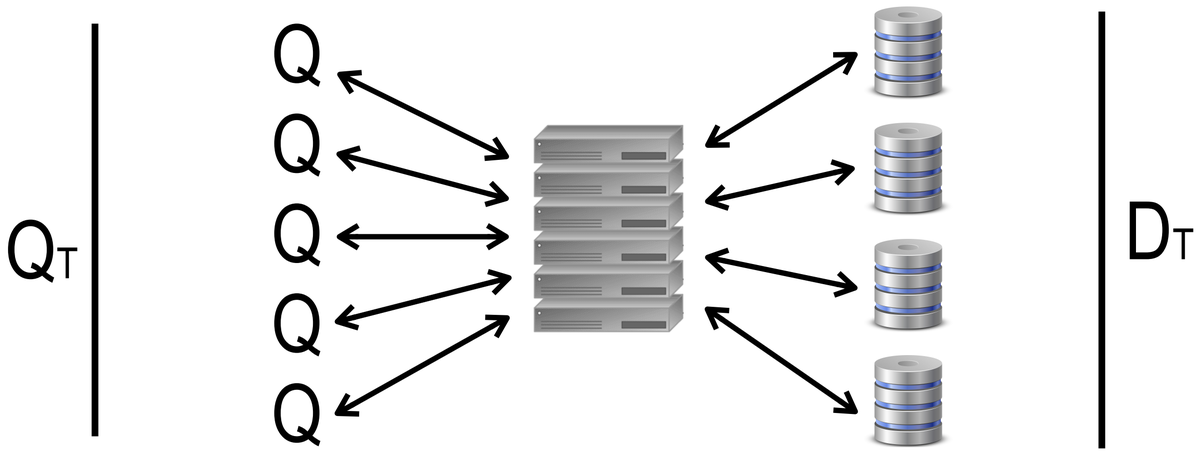

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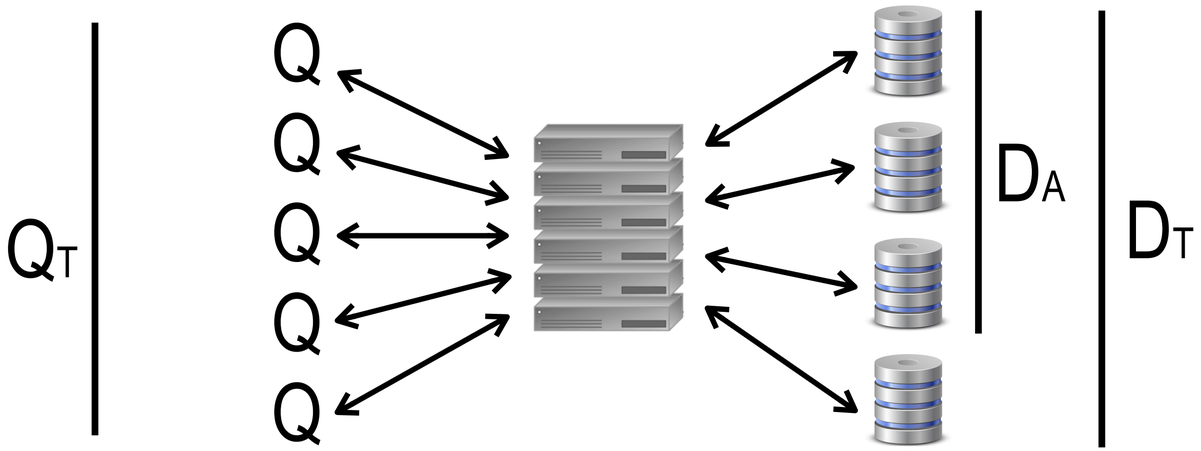

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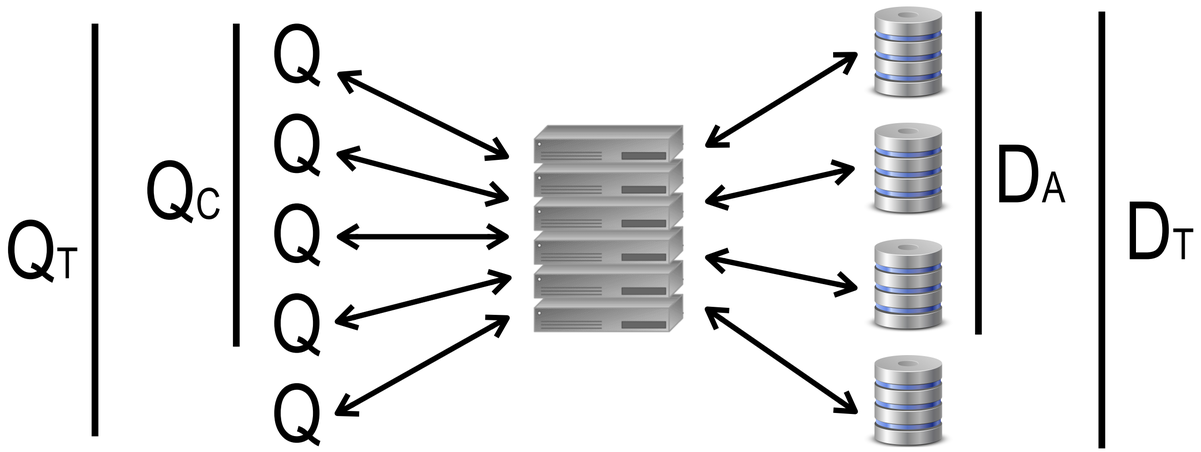

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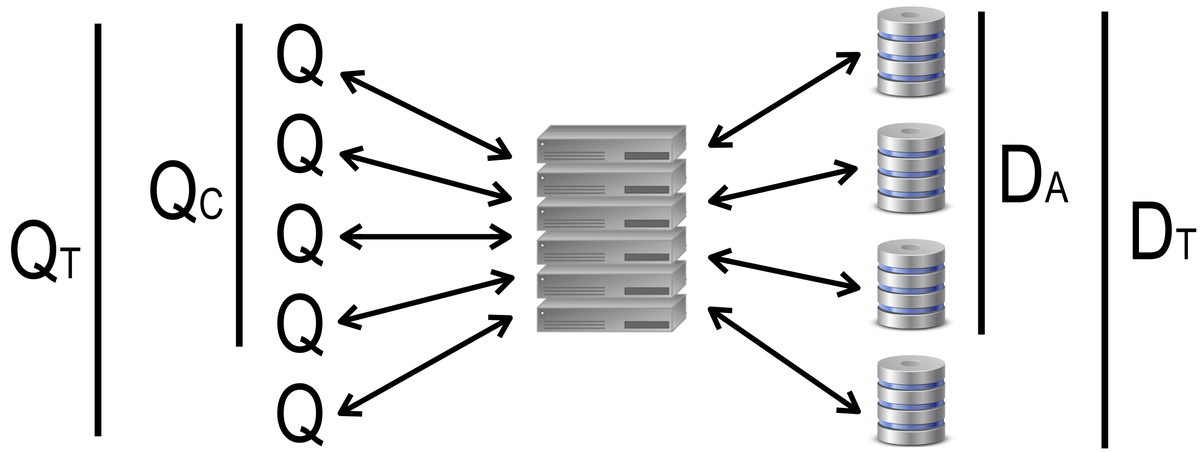

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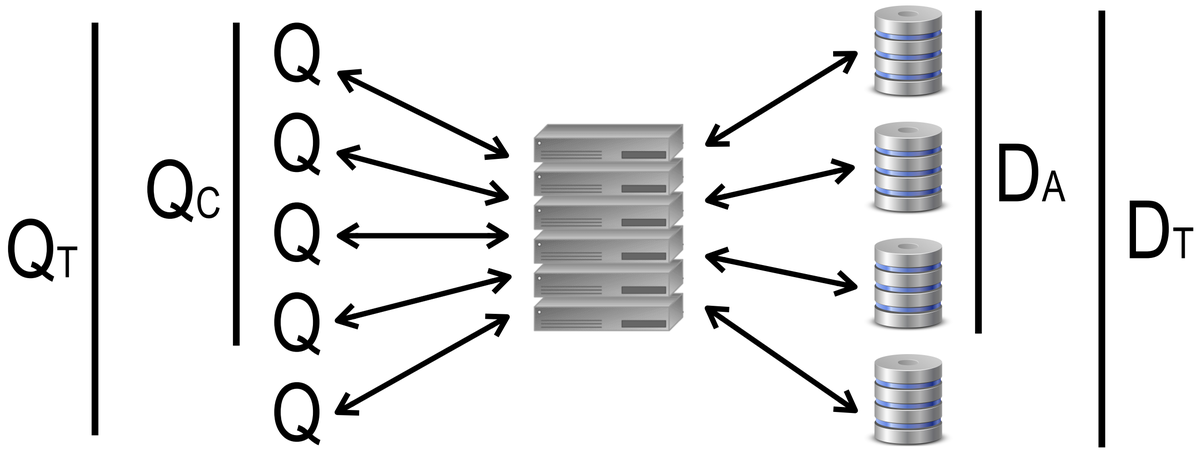

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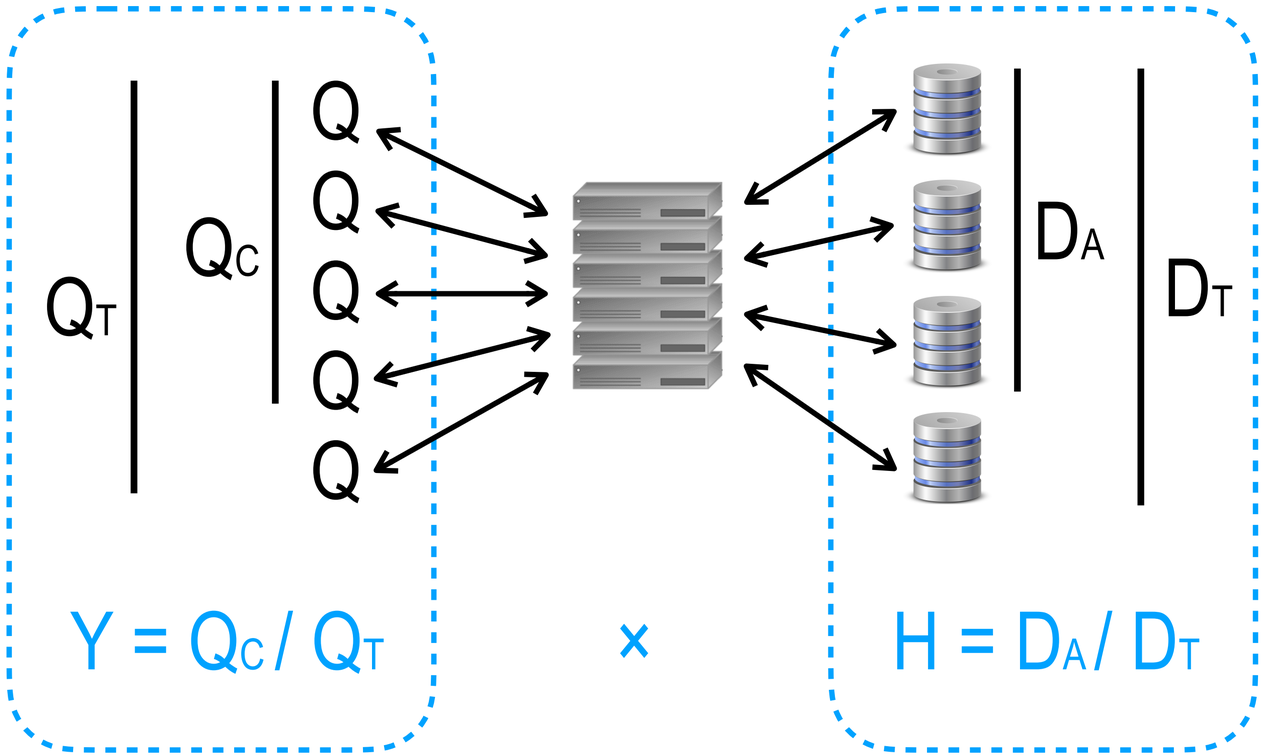

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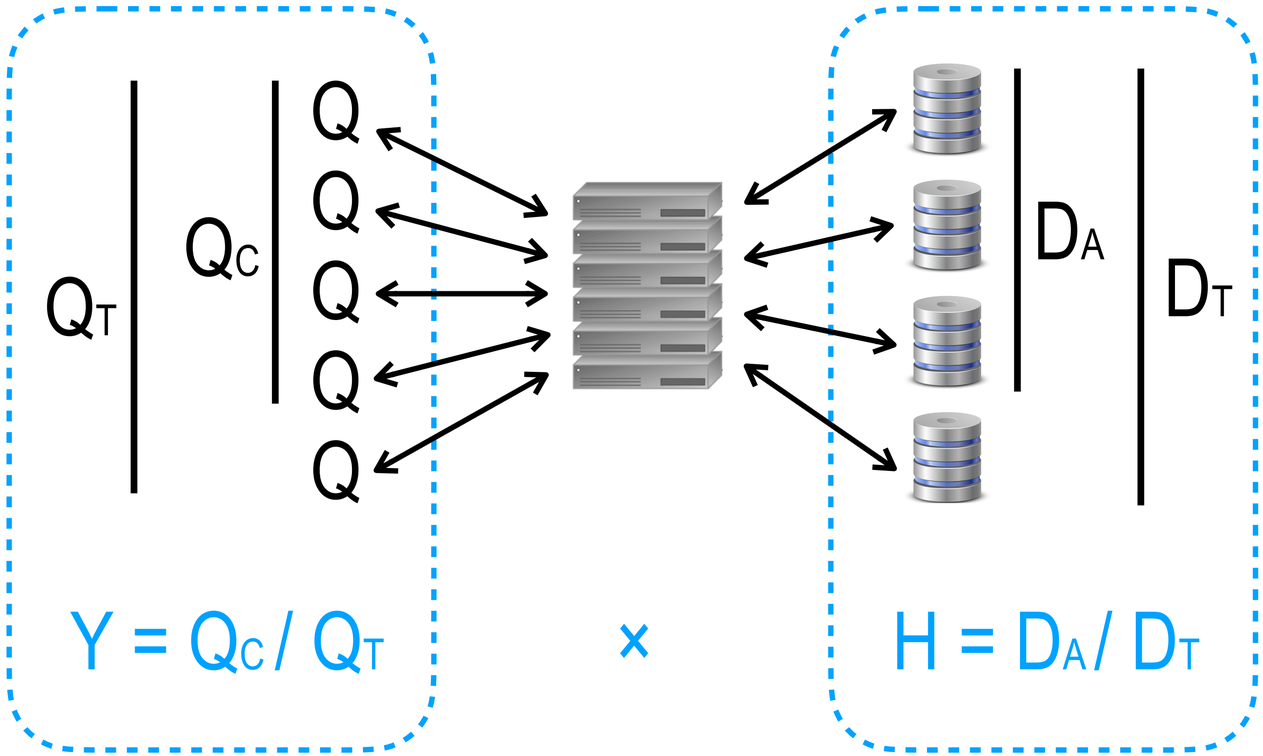

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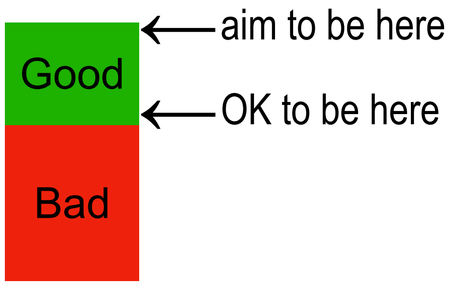

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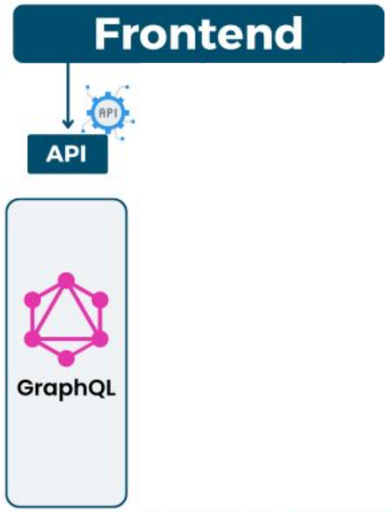

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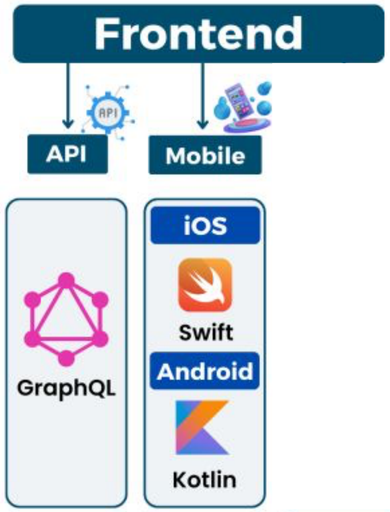

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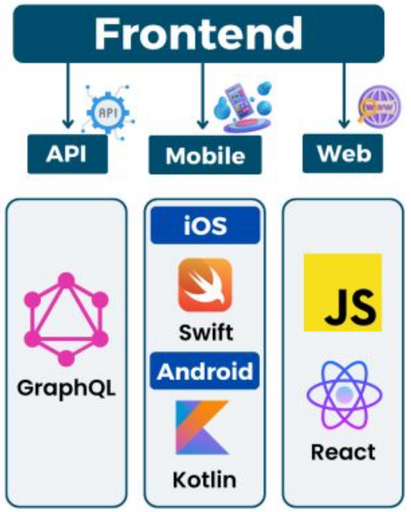

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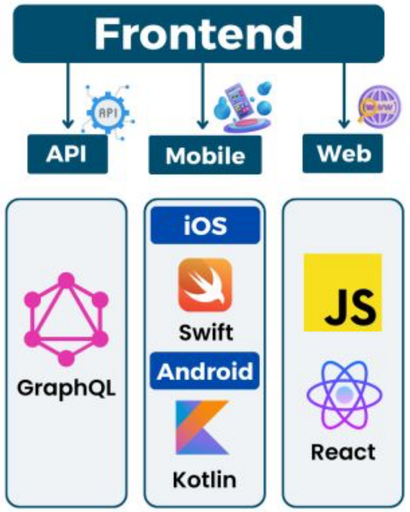

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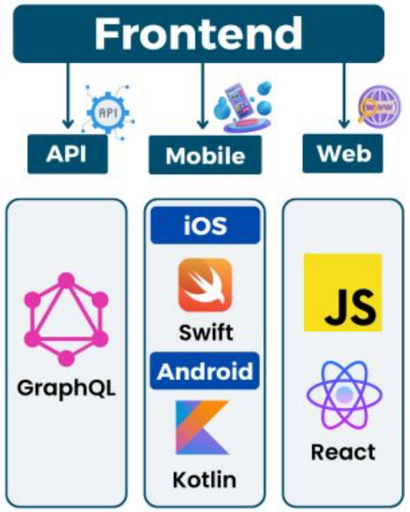

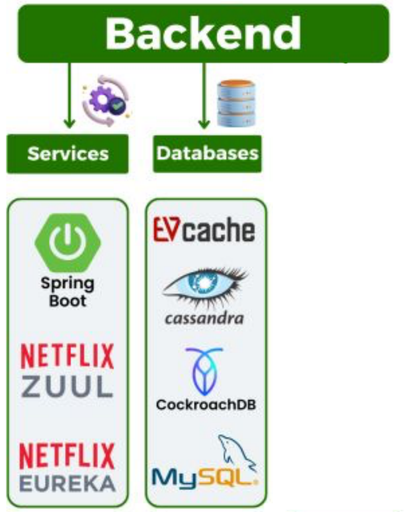

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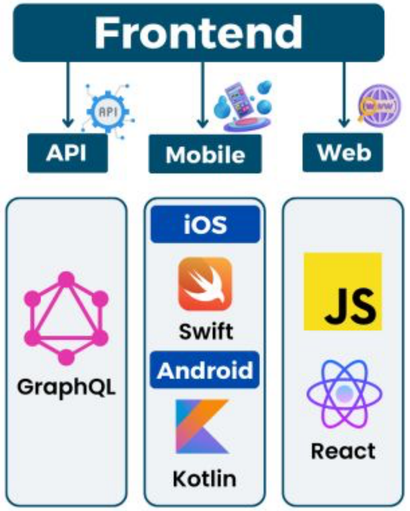

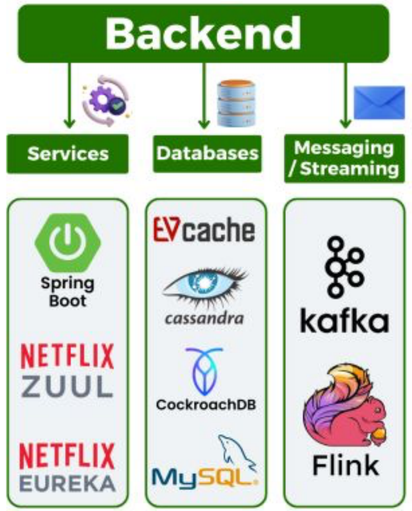

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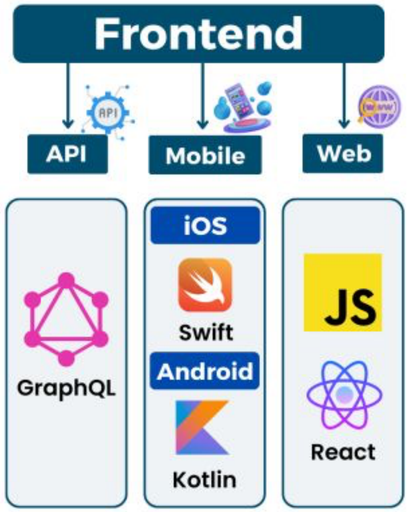

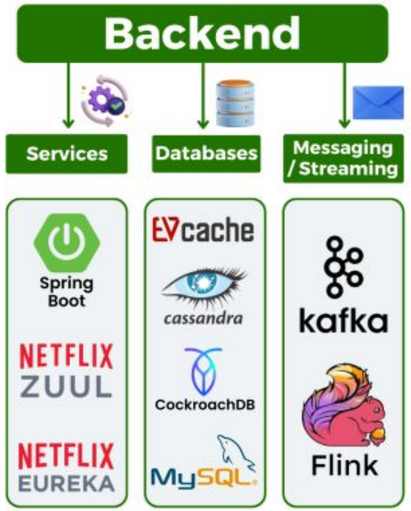

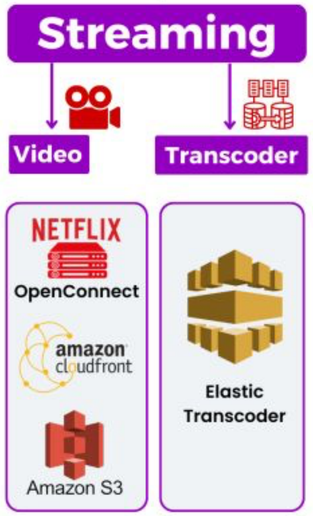

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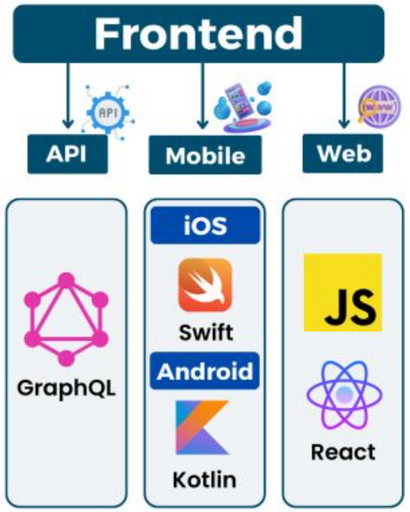

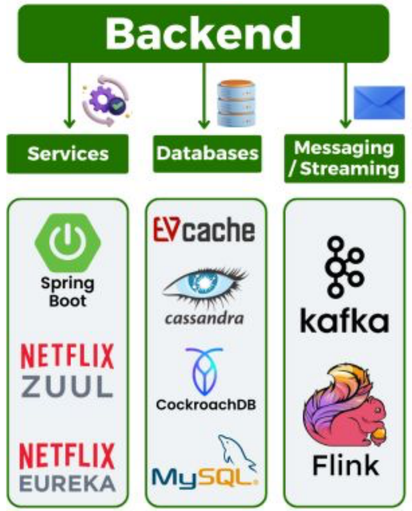

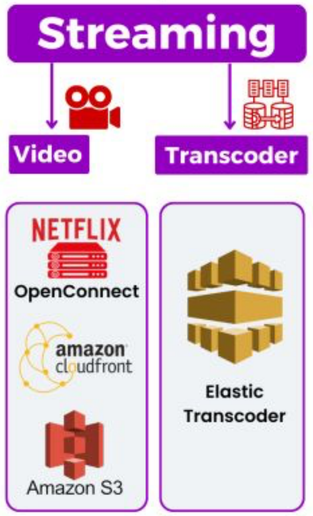

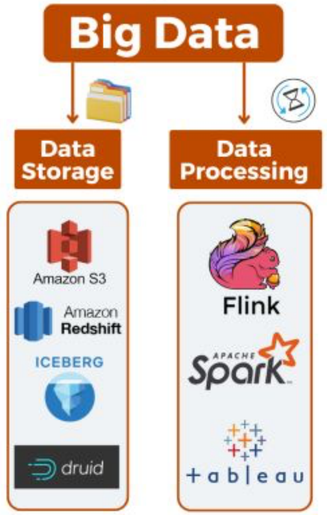

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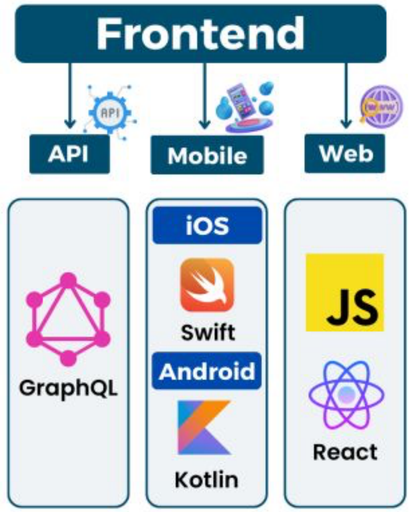

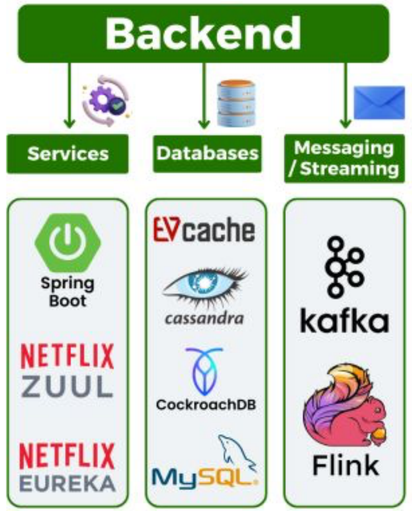

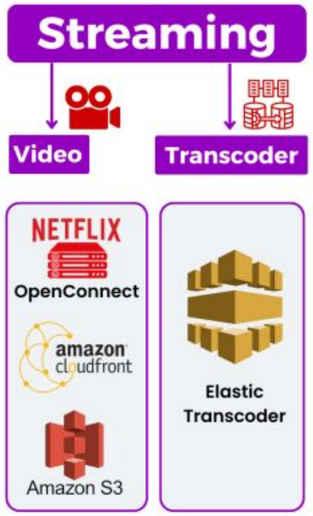

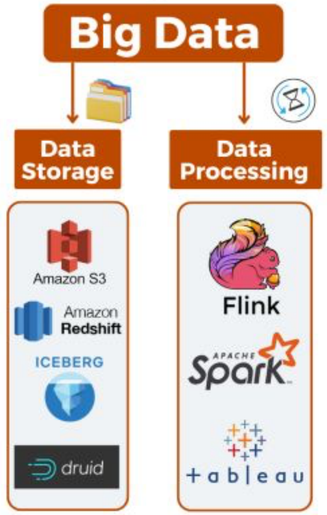

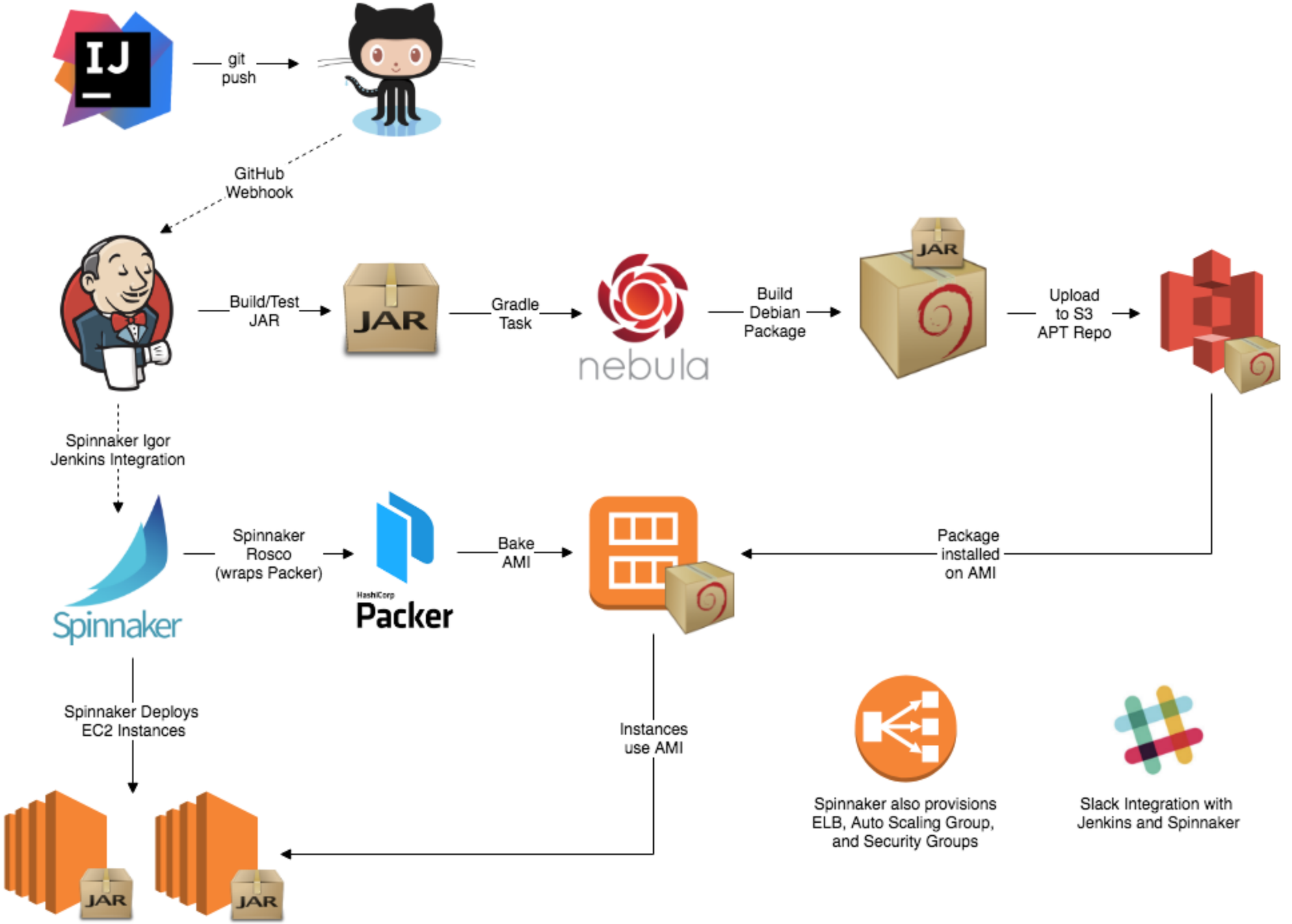

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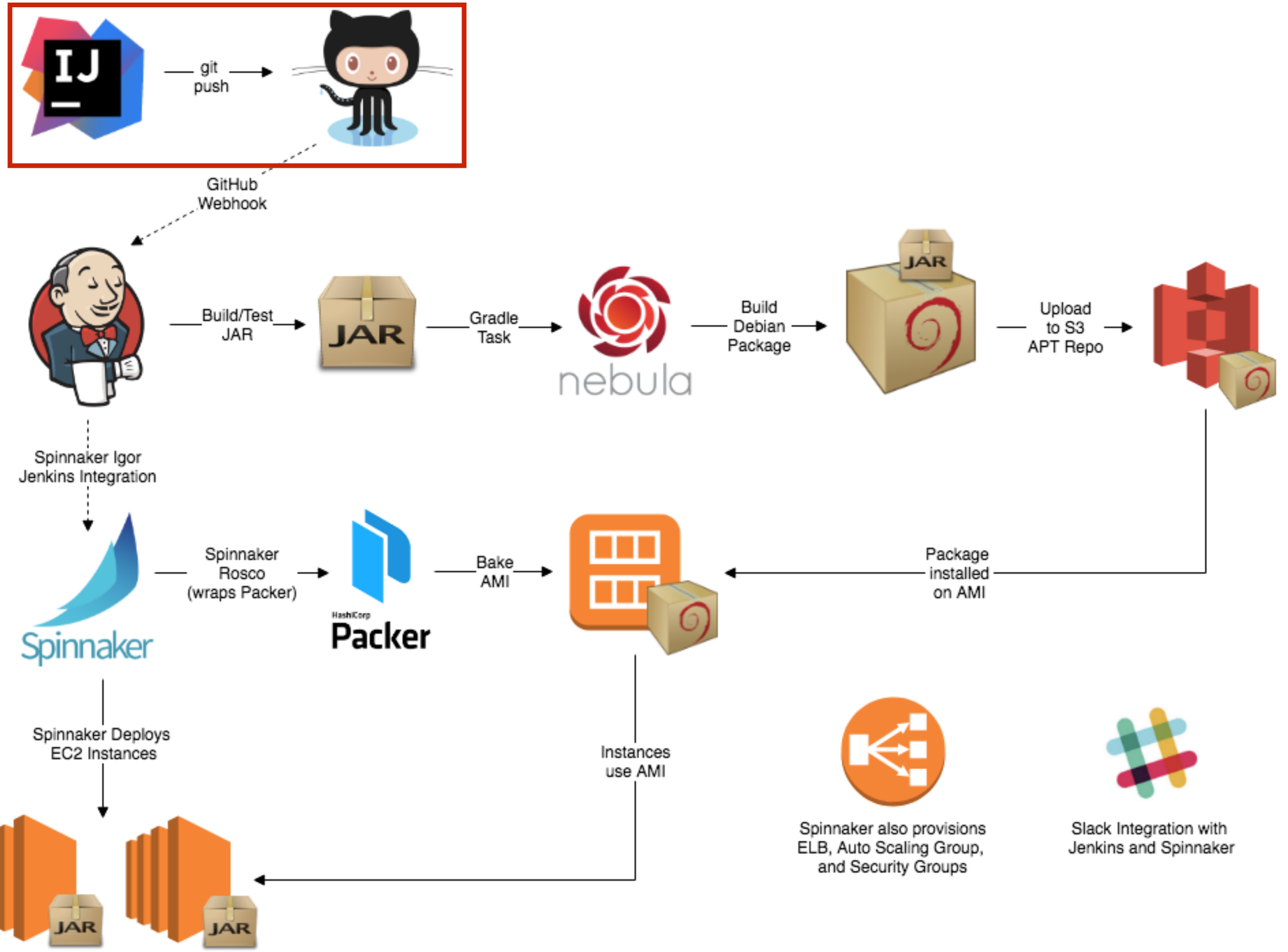

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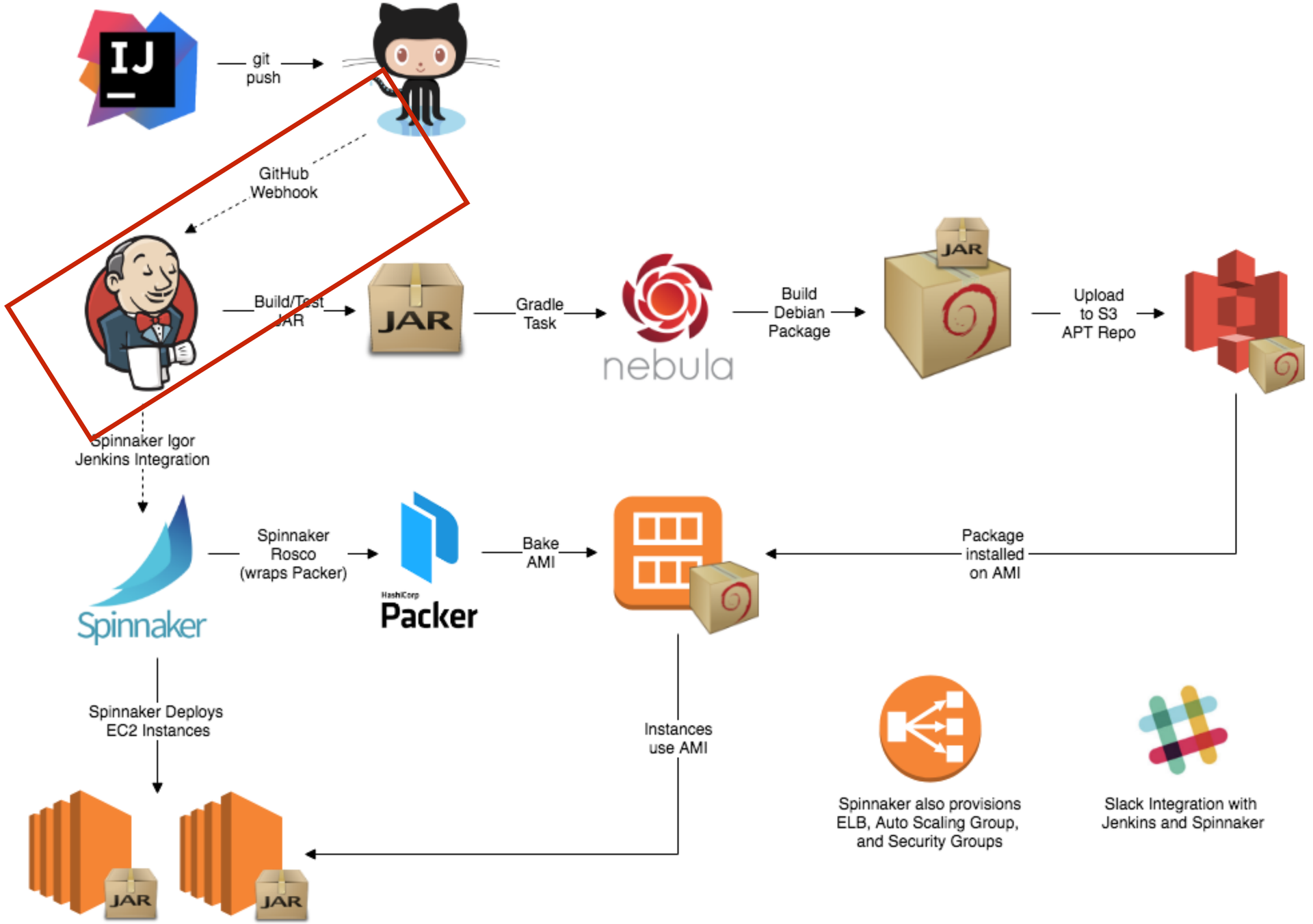

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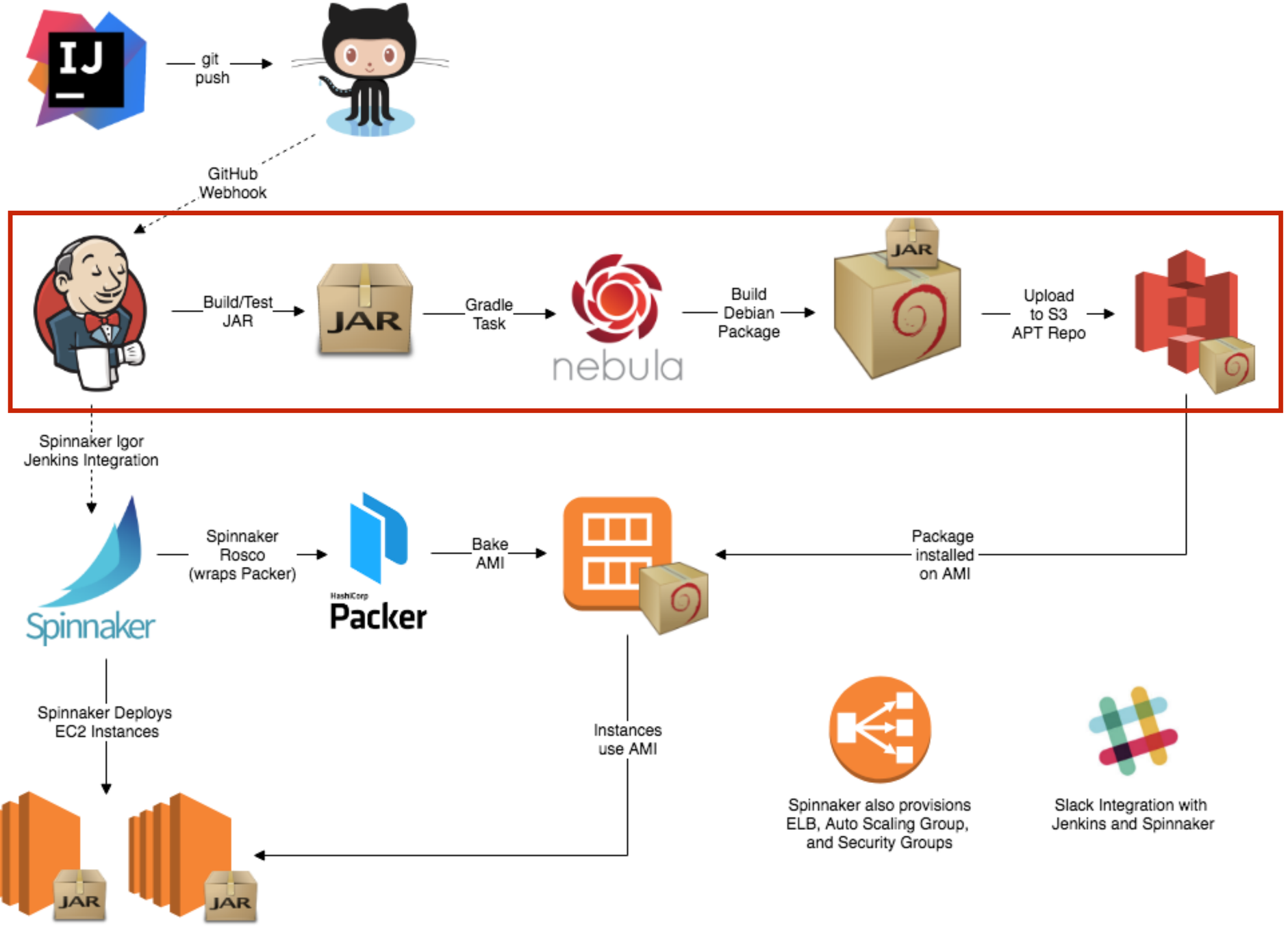

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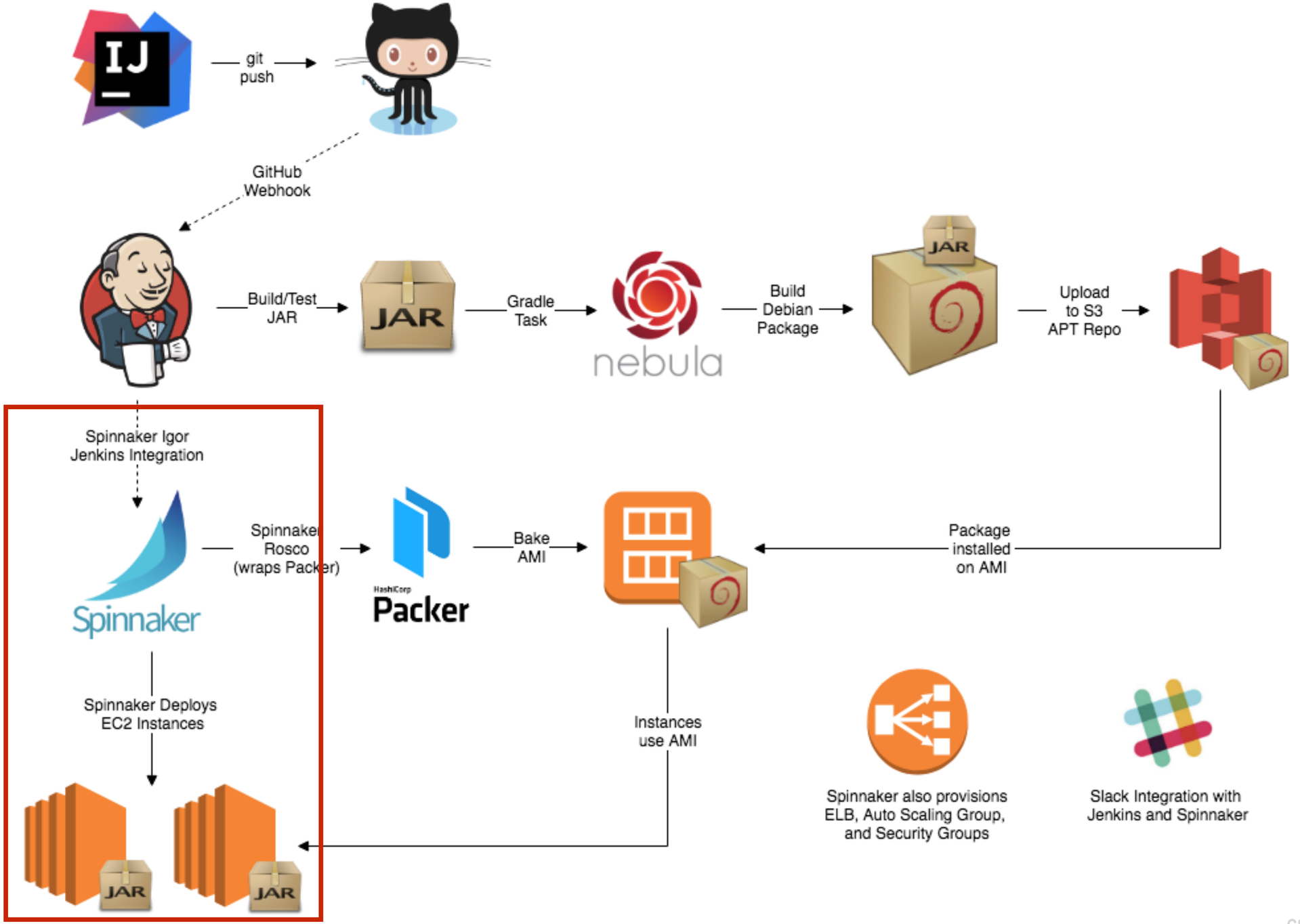

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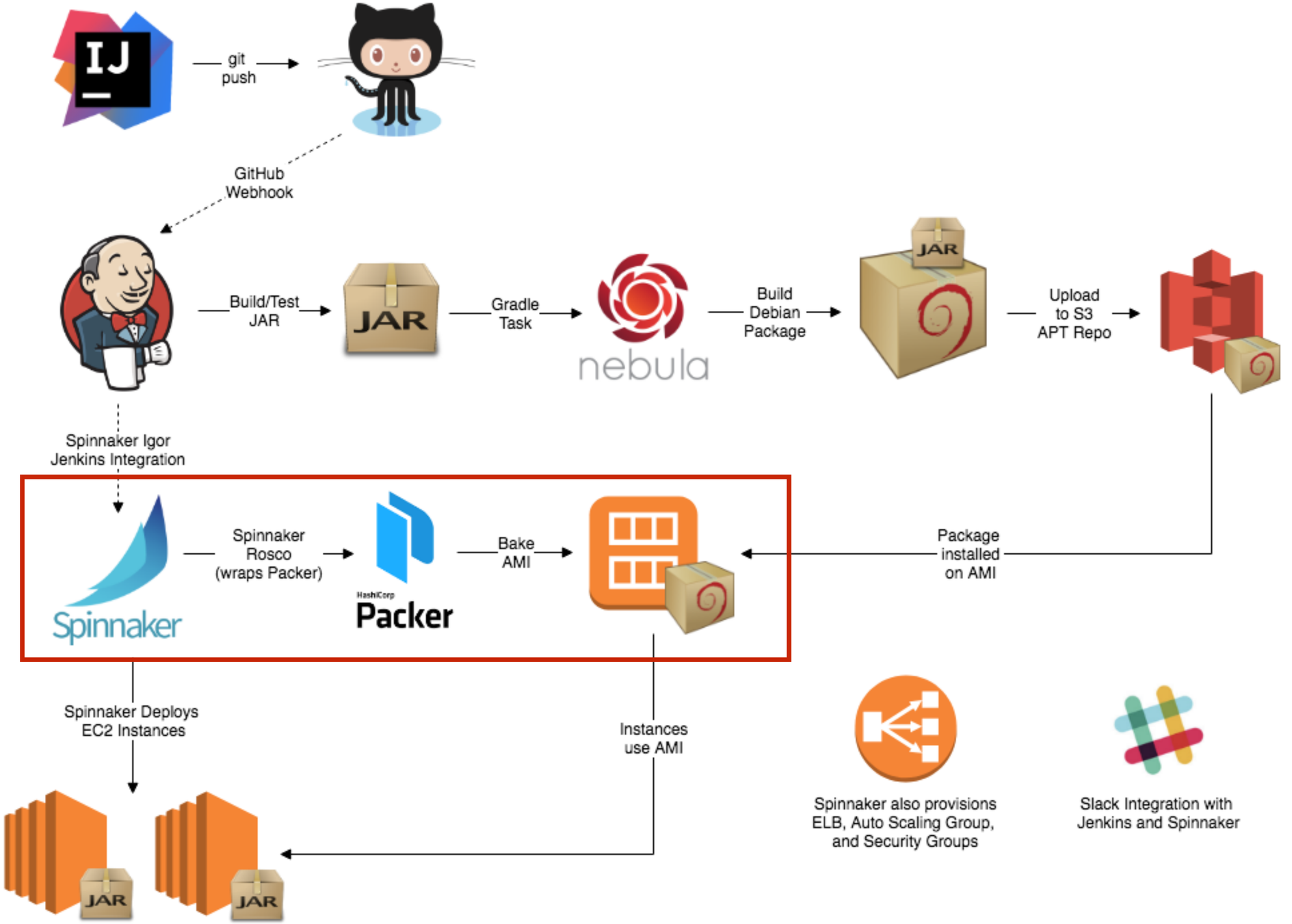

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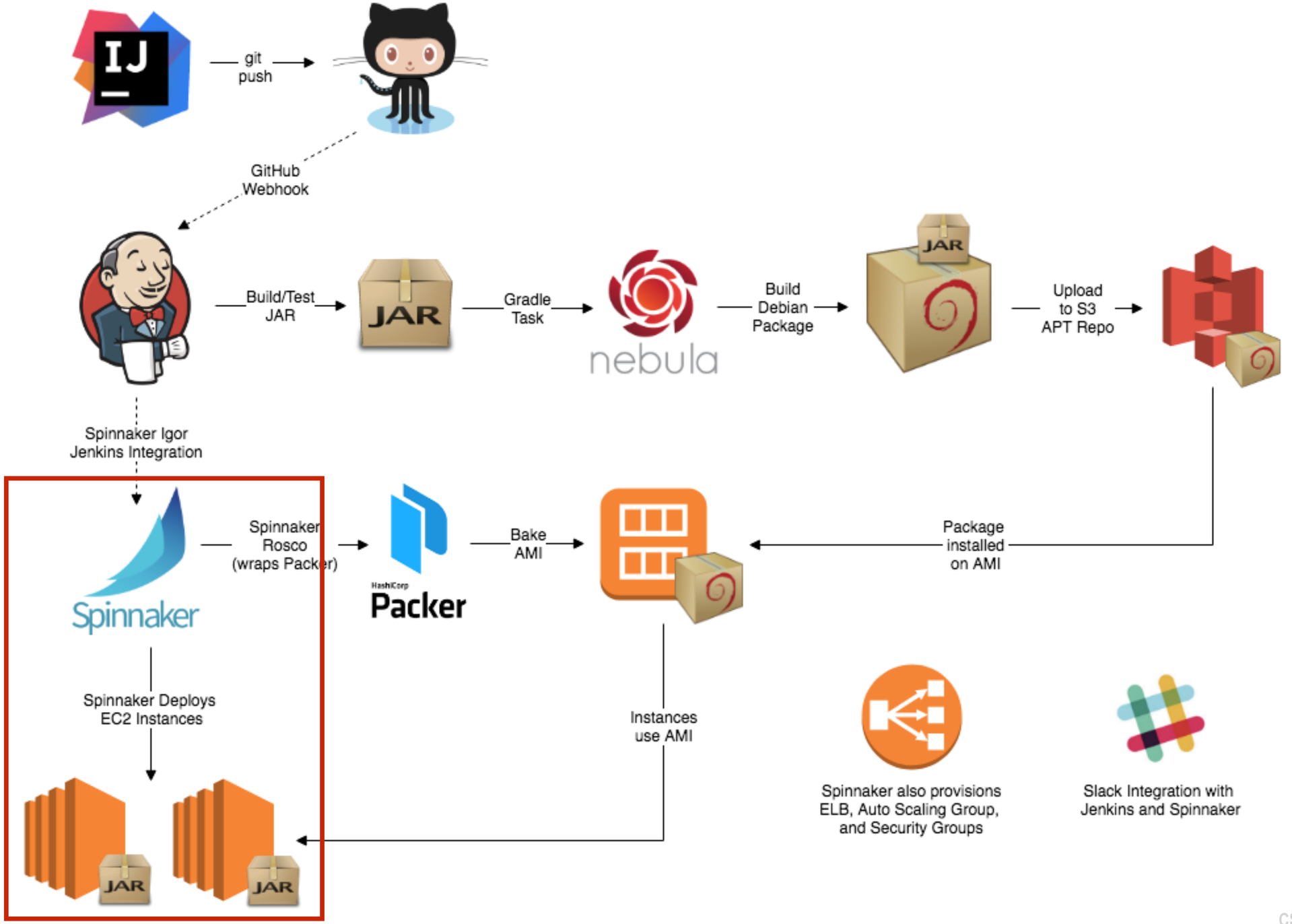

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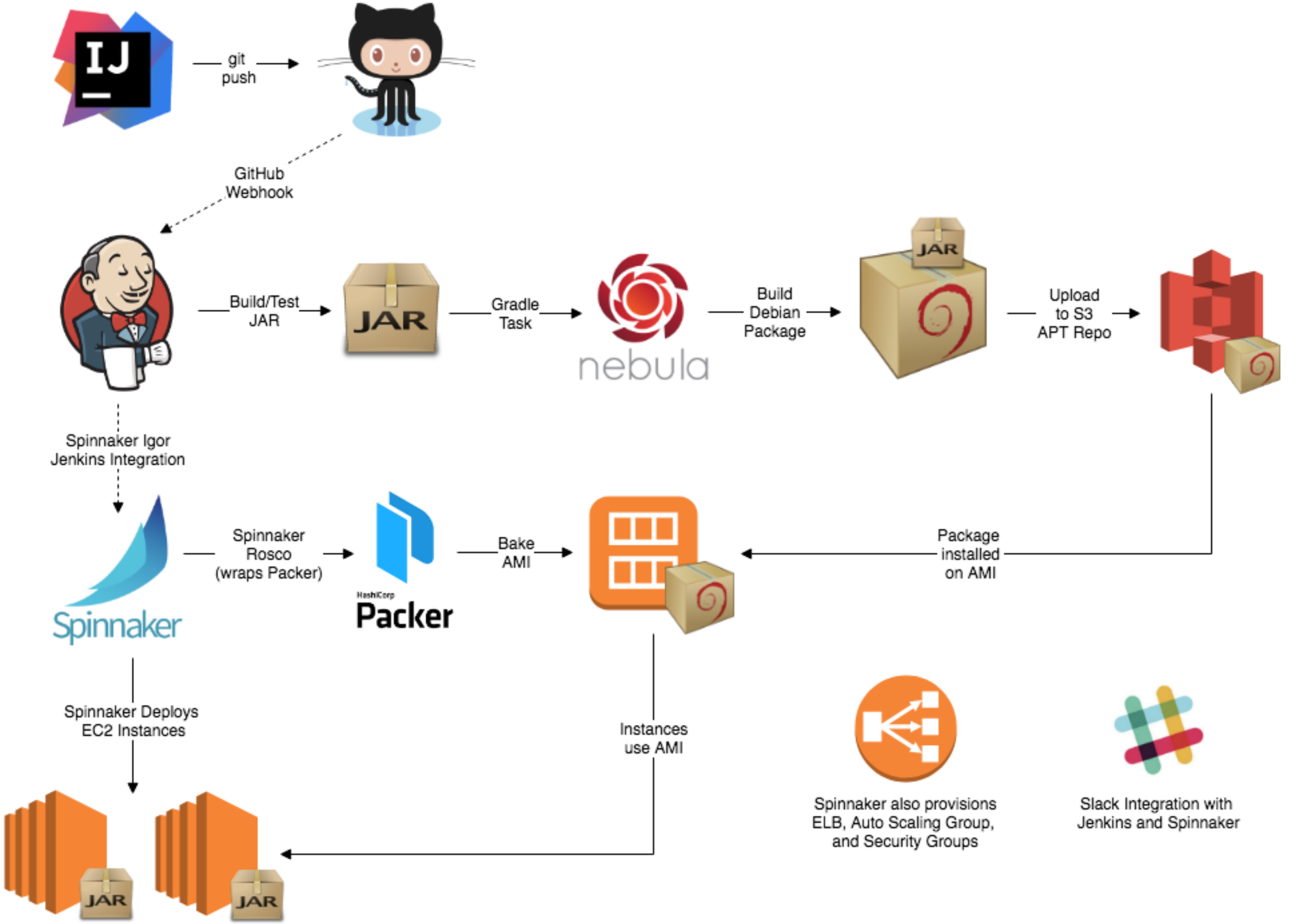

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Randomly disables production instances

Janitor Monkey

Identifies and disposes unused resources

Chaos Kong

Drops a full AWS Region

Conformity Monkey

Shuts down instances not adhering to best-practices

Chaos Gorilla

Outage of entire Amazon Availability Zone

Security Monkey

Finds security violations and vulnerability

NETFLIX SIMIAN ARMY

@geosley

Doctor Monkey

Taps into health checks and fixes unhealthy resources

Latency Monkey

Simulate degradation or outages in a network

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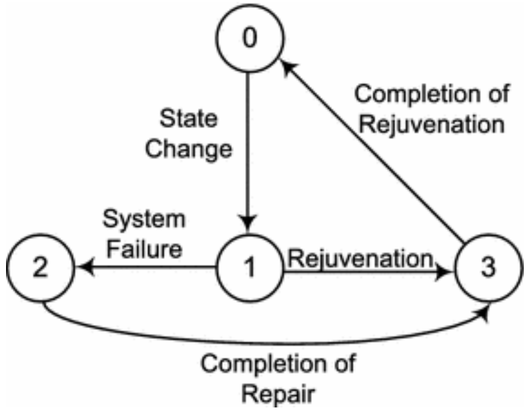

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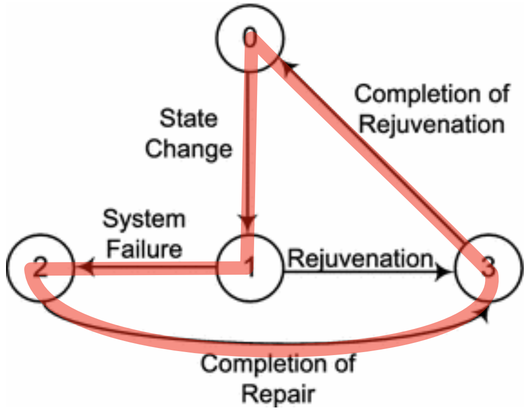

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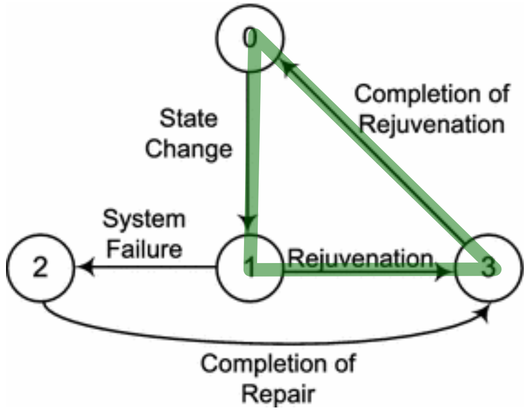

How to reduce unavailability by 10× ?

$$\text{Unavailability} \cong \frac{\text{MTTR}}{\text{MTTF}} \uparrow\times 10$$

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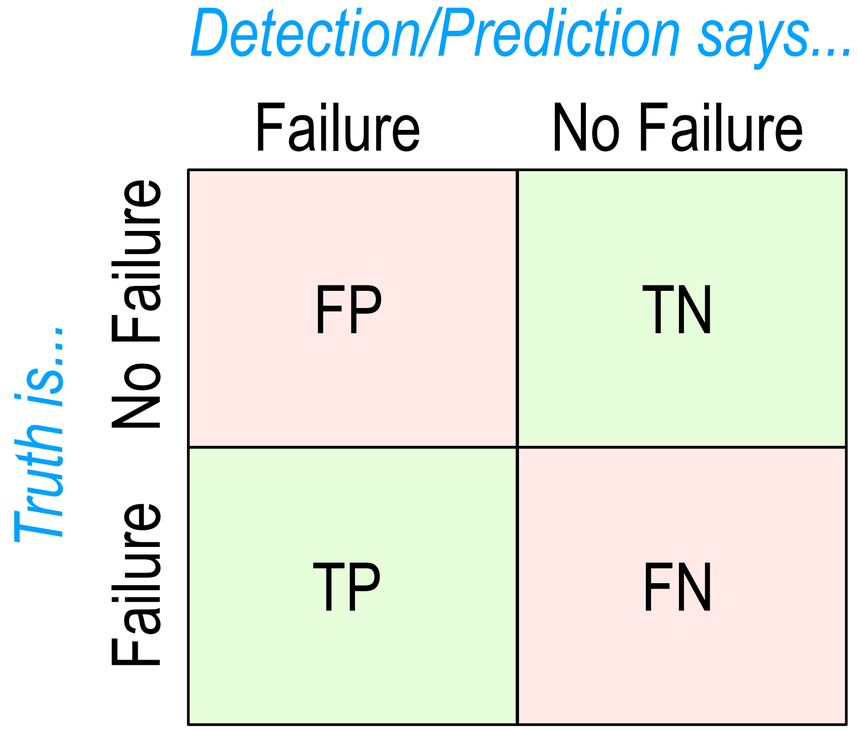

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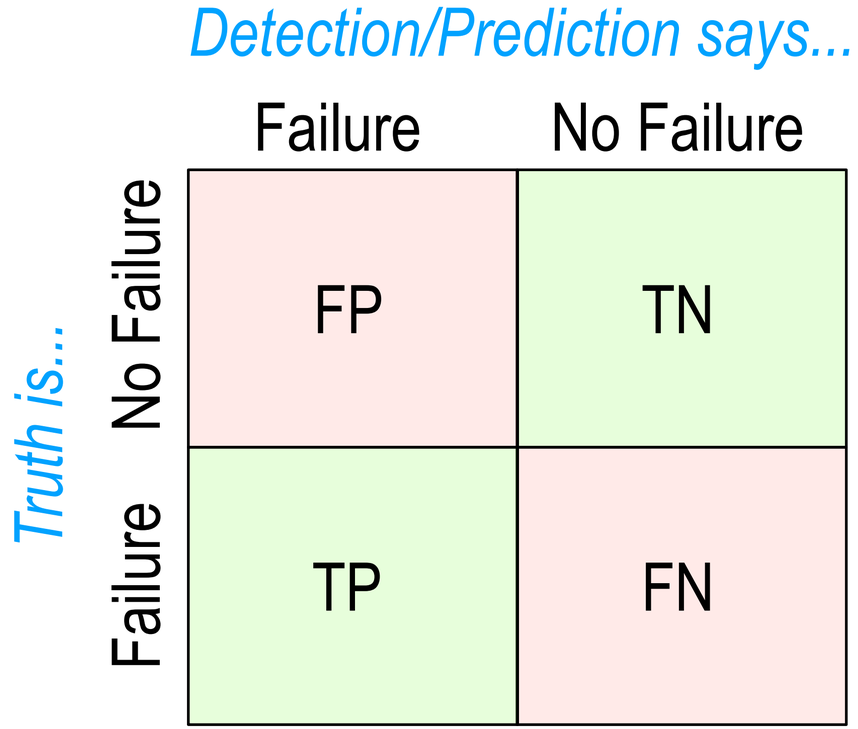

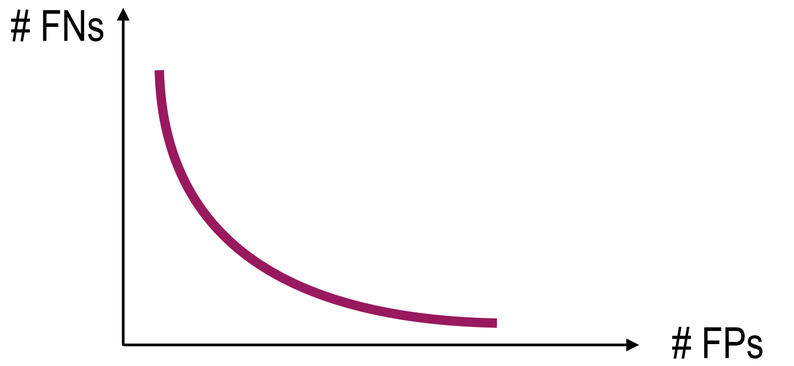

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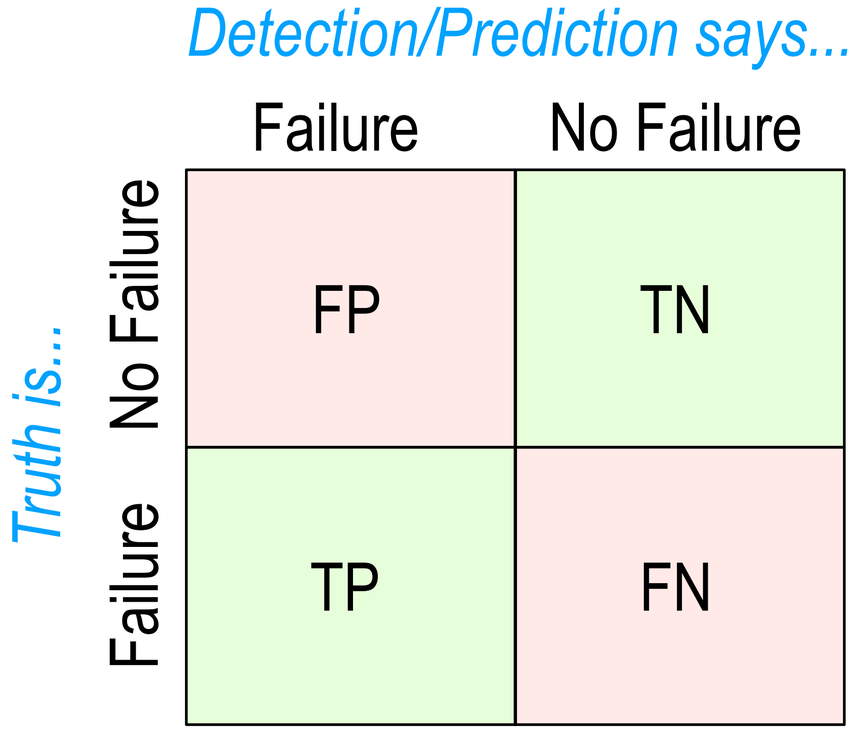

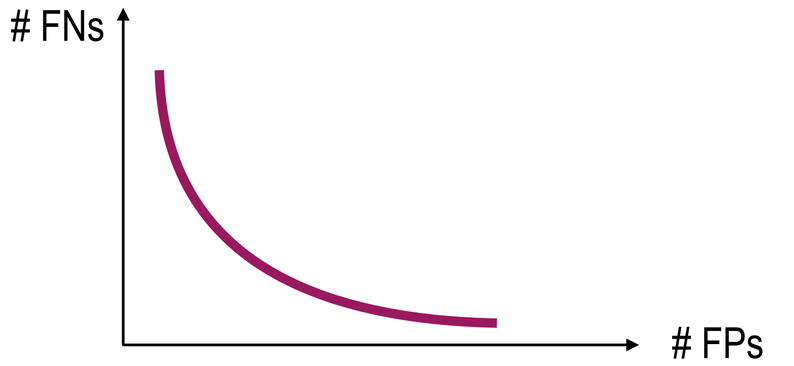

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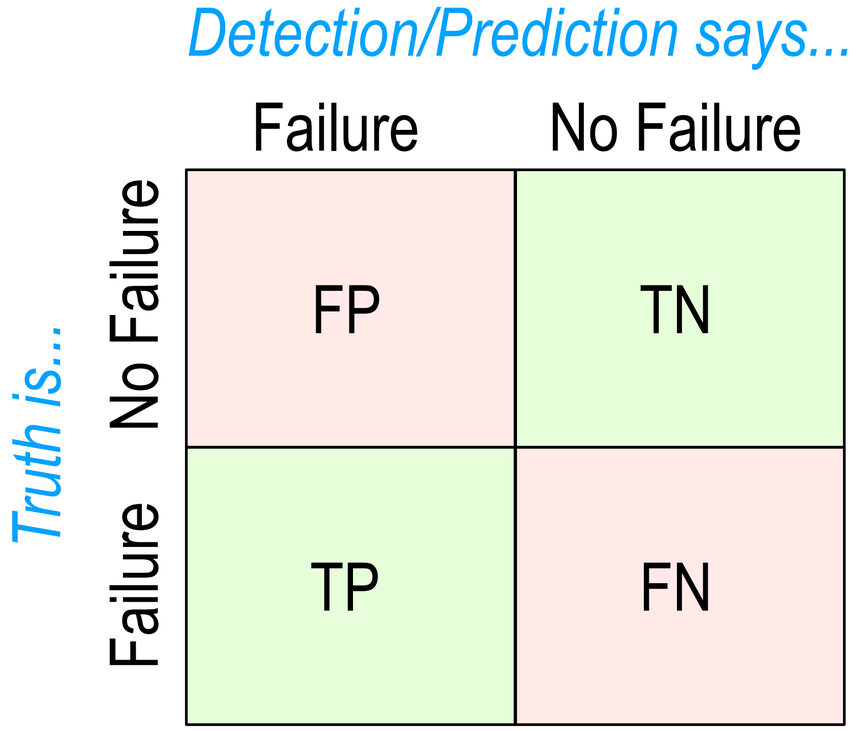
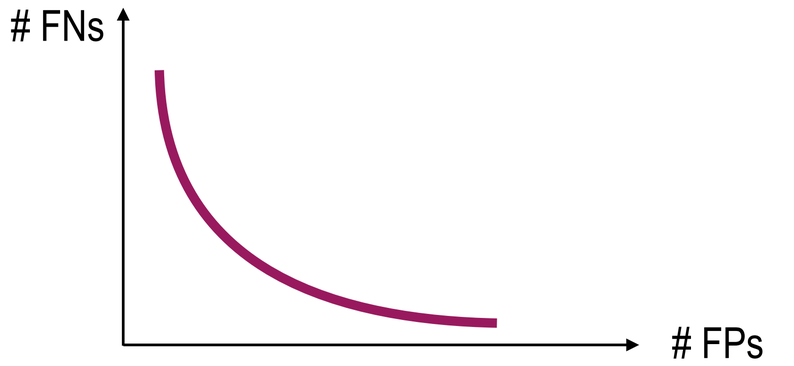
- How to reduce T_{repair}?
  - Mostly app-specific
  - Reboot is universal





Reboot-based Recovery

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Step 1: Modularize system into fine-grained components

- Components with individual loci of control
  - *Well defined interfaces*
  - *Small in terms of program logic and startup time*

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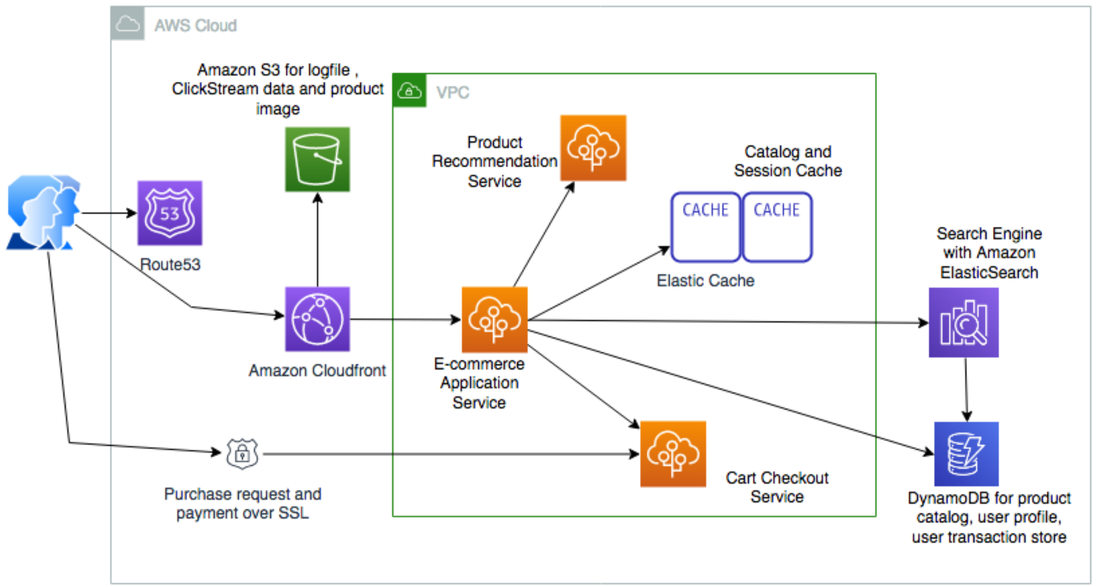

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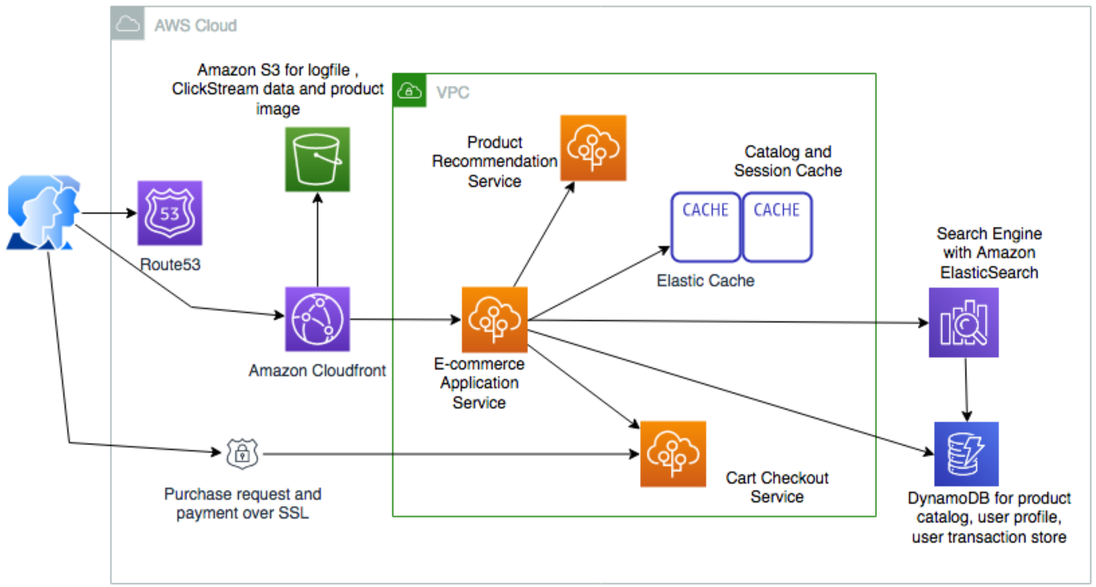

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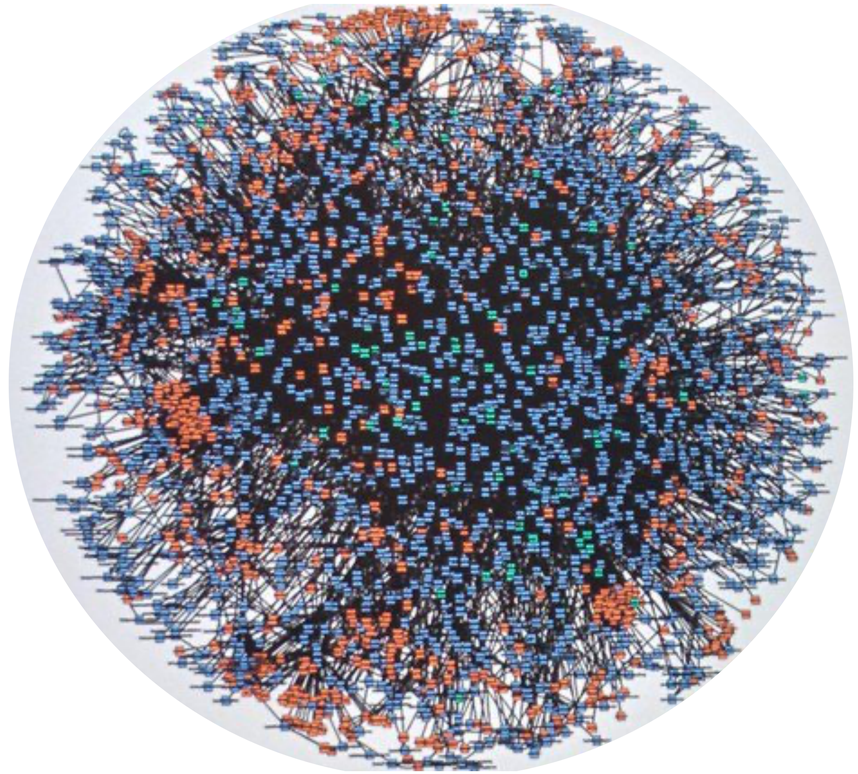

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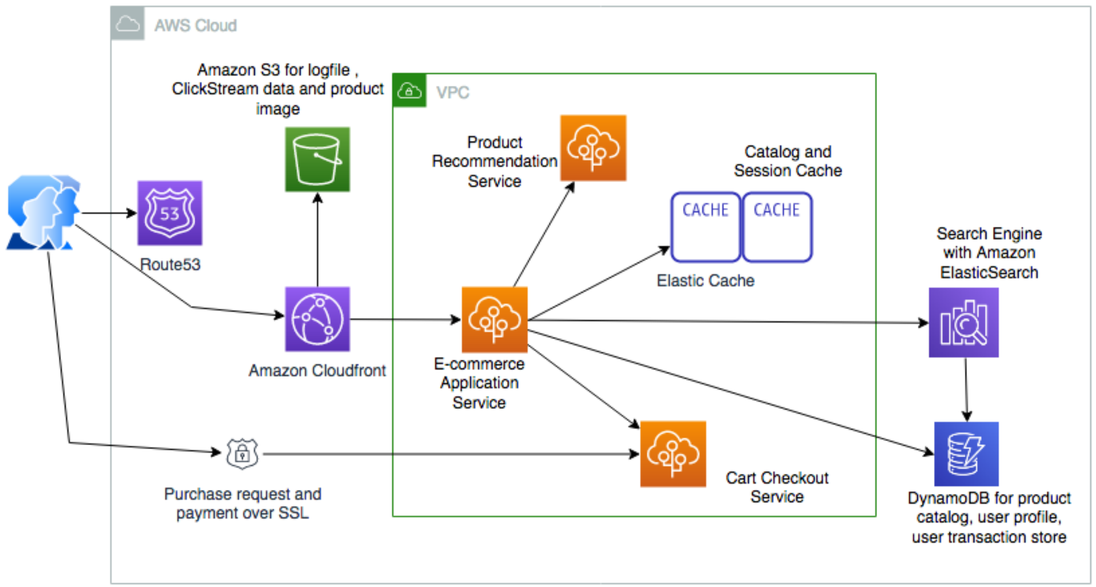
- $T_{reboot} = T_{restart} + T_{initialization}$



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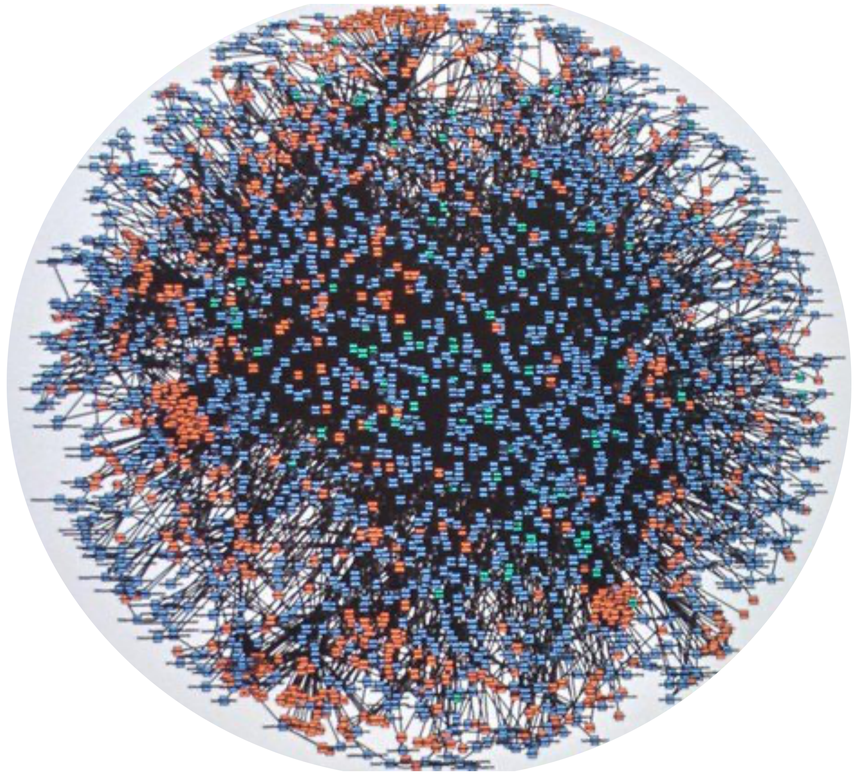

https://twitter.com/Werner/status/741673514567143424/photo/1

Problems with microrebooting

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- Separate data recovery from app recovery => do each one better

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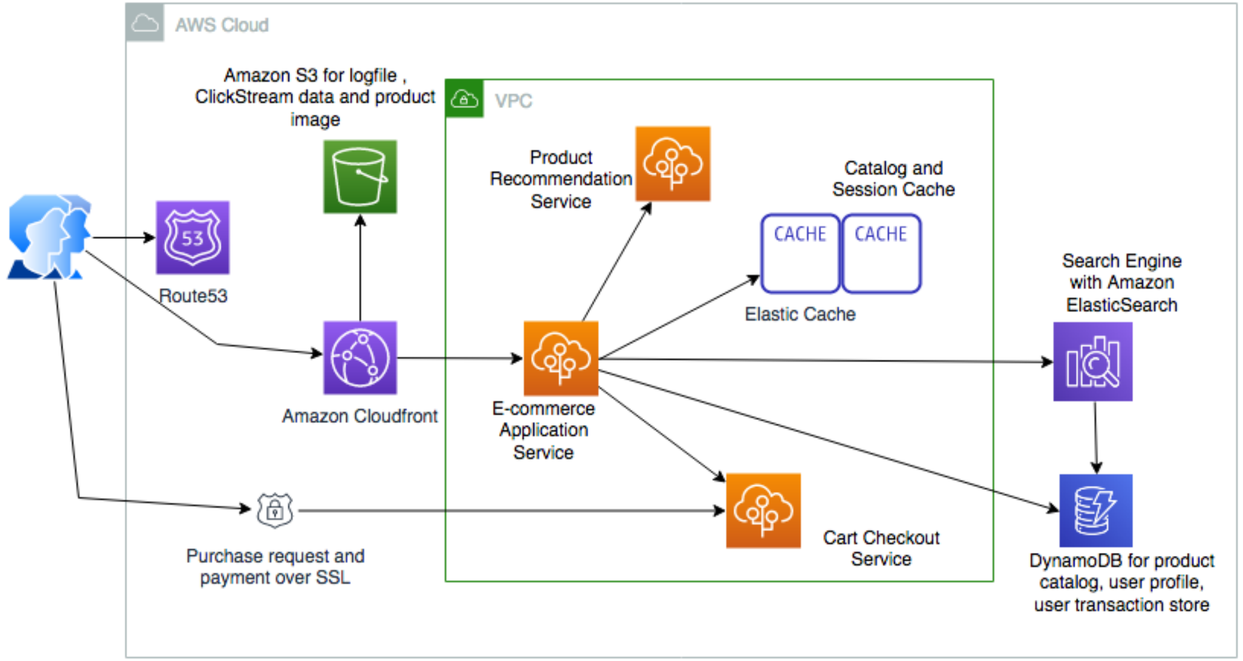

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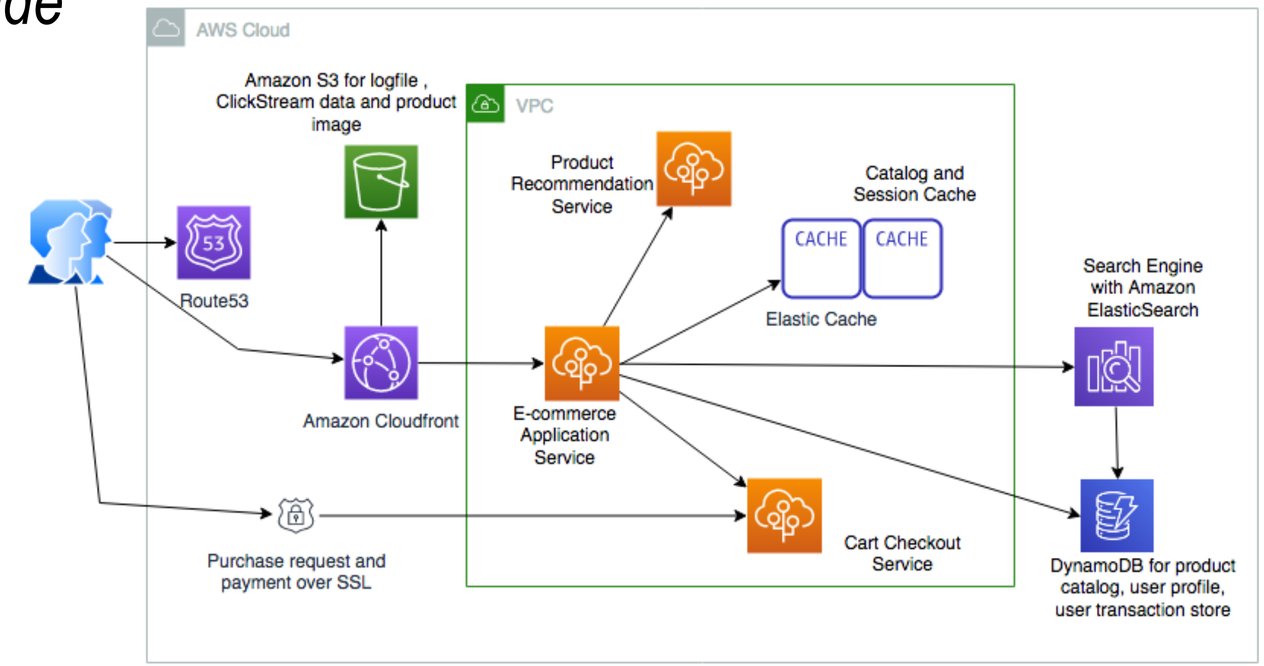
Functional decoupling

- Goal
  - *reduced disruption of system during restart*
- No direct references (e.g., no pointers) across component boundaries
  - *Store cross-component references outside component*
    - Naming indirection through runtime
    - Marshall names into state store



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- Goal: avoid resource leakage without fancy resource tracking
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  - *CPU execution time*
- Requests carry TTL => automatically purged when TTL runs out

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- Interact via timed RPCs or equivalent
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- Action depends on whether RPC is idempotent or not

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