University of Oviedo

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EN
English

School of Computer Science

Allocation

SOFTWARE
ARCHITECTURE

School of Computer Science

2024-25

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Allocation

Relationship between Software and its environment

Where does each component run?

- Infrastructure?
- Deployment?

Allocation

- Packaging, distribution and deployment
  - Software computation options
  - Execution environments
  - Continuous delivery and deployment pipeline
- Software in production
  - Software in production patterns
  - Software in production testing
  - Logging & Monitoring
  - Incidents & post-mortem
  - Chaos engineering

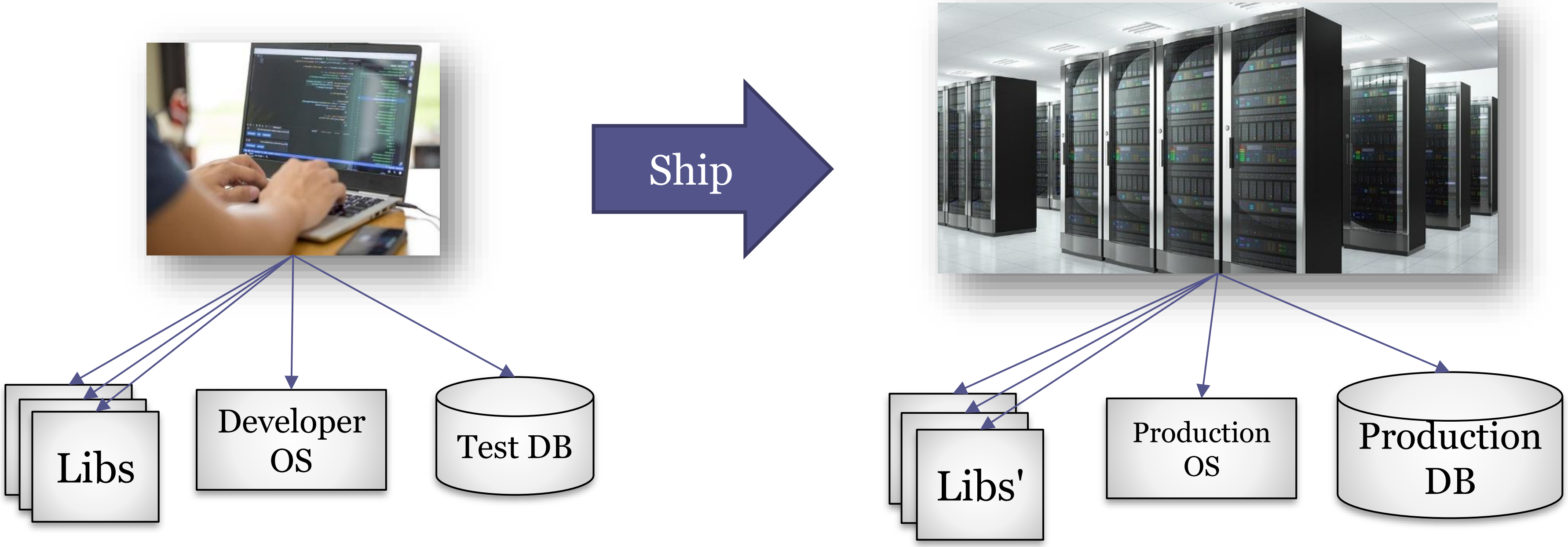
Packaging, distribution and deployment

Packaging

- Create an executable from source code
- A typical package consists of:
  - Compiled code
    - Even for interpreted languages: Transpiled, obfuscated & minimized
  - Configuration files
    - Environment variables
    - Credentials, etc.
  - Libraries & dependencies
  - User manuals & docs
  - Installation scripts

The problem of shipping software

- Most software is not standalone
- Lots of dependencies
  - Libraries, shared libraries, operating system libraries, ...
- Developer's environment ≠ Production environment



Ship

Libs

Developer OS

Test DB

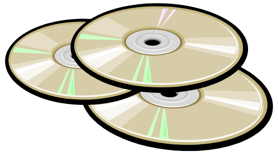
Libs'

Production OS

Production DB

Distribution channels

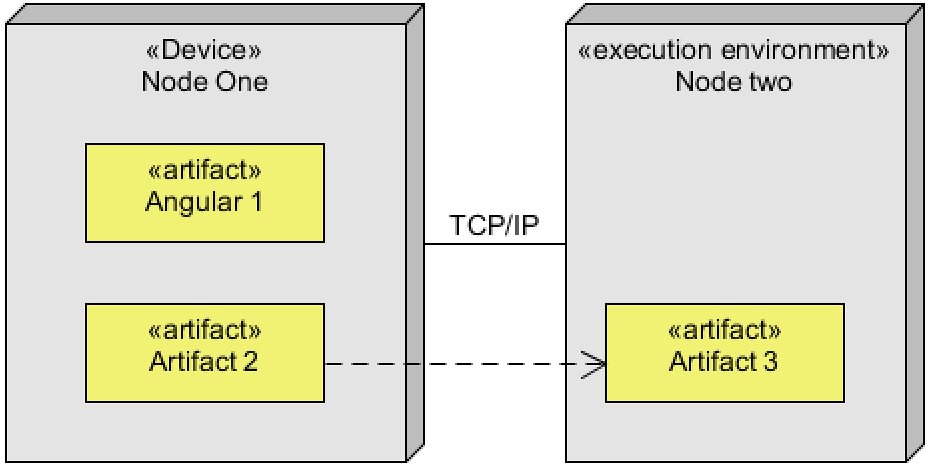
- Physical distribution
  - CDs, DVDs, ...
- Web based
  - Downloads, FTP, ...
- Application markets
  - Linux packages
  - App stores:
    - AppStore,
    - Google Play,
    - Windows Store



Deployment

Deployment view

- UML has deployment diagrams
- Artifacts associated with computational nodes
- 2 types of nodes:
  - Device node
  - Execution environment node



Software computing options

On-premises

Cloud computing

Edge computing

Fog computing

On premises computing

Software run *in the building*

Client's computers/data center

Advantages

- More control on hardware environment
  - Upgrades, customization
- Security
  - When it is well configured

Challenges

- Requires hardware investment
  - Which hardware is required?
  - Return of inversion?
- Maintenance costs
  - Also costs on licenses, space,...
- Sys. admin. skills required

Cloud computing

Computer resources on demand

Software as a service (SaaS)

Advantages	Challenges
No initial investment	Security
Less expensive	Dependency on cloud providers
Affordable access to expensive hardware	Varying costs (possible surprises)
No need for sys. admins. skills	Requires configuration skills

Pets vs cattle metaphor

In the old way of doing things, we treat our servers like pets, for example Bob the mail server. If Bob goes down, it's all hands-on deck. The CEO can't get his email and it's the end of the world.
In the new way, servers are numbered, like cattle in a herd.
For example, www001 to www100. When one server goes down, it's taken out back, shot, and replaced on the line.

"Pet" server

Unique and indispensable
GUI driven
Hand crafted
Reserved
Scale-up
. . .

"Cattle" servers

Disposable, one of the herd
API driven
Automated
On demand
Scale-out
. . .

More info: http://cloudscaling.com/blog/cloud-computing/the-history-of-pets-vs-cattle/

Edge computing

Computing done at customer devices

- Connected devices process data closer to where it is created
- Example: IOTs, Connected cars, ...

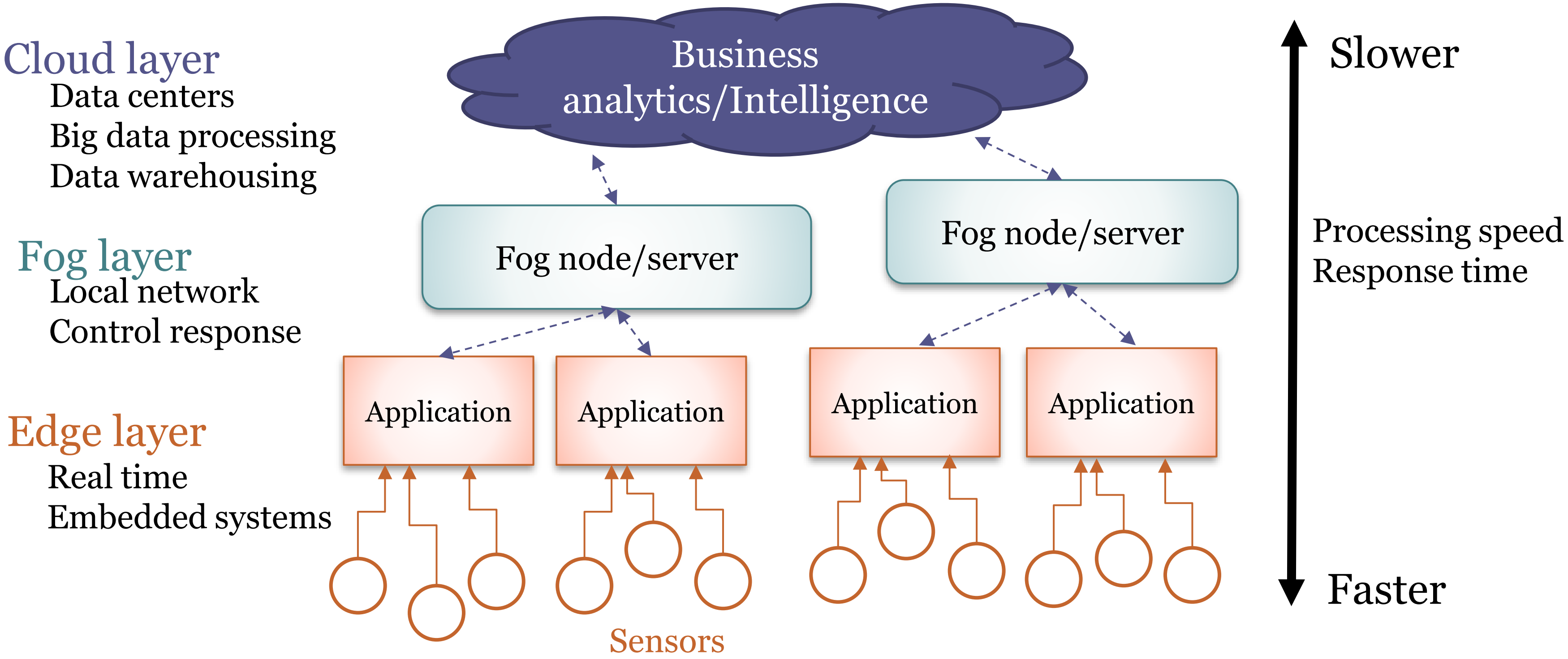
Advantages	Challenges
Faster response (real time)	Less computing power
Micro data storage	No access to required data
On-premises visualization	Embedded systems development
Independency (no network involved)	

Fog computing

Computating at intermediate nodes

Local Area Network

Advantages	Challenges
Local network Control response	Complexity Security

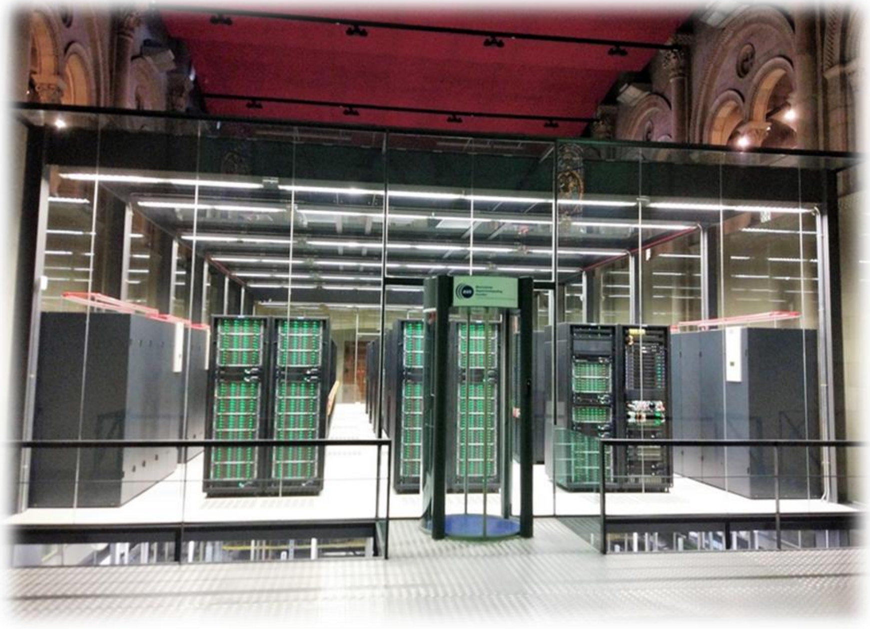


Execution environments

- Where will the software run?
- Which dependencies does it have?
  - Operating systems
  - Shared libraries
- Several options
  - Physical Hosts
  - Virtual machines
  - Containers

Physical hosts

- Lots of possibilities
  - Commodity computer
  - Super-computers
  - Server farms
  - End-user devices



The MareNostrum 4 supercomputer (2017)
Source: Wikipedia

Advantages	Challenges
Control Performance	Reliability Portability

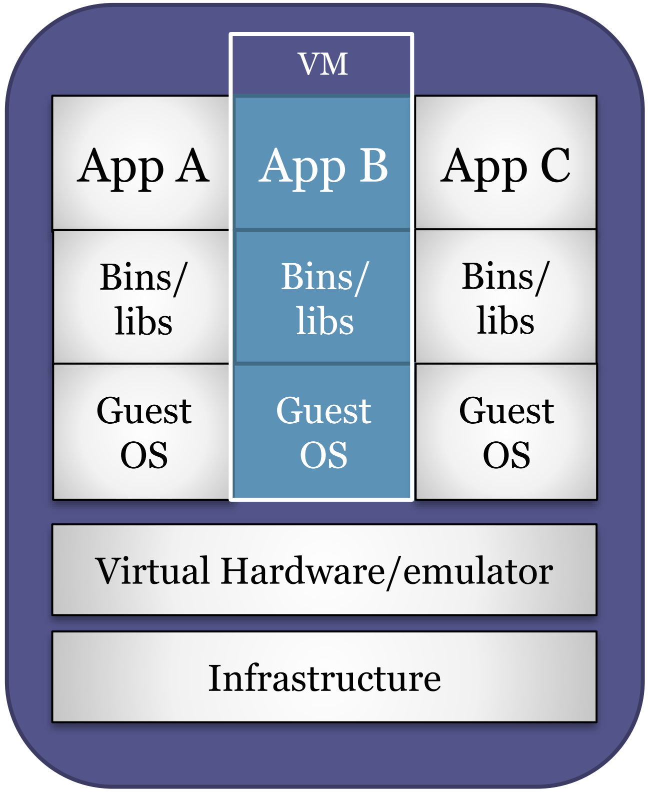
System Virtual machines

- Isolated emulation of a real machine
  - Virtual hardware emulator
  - Run multiple operating systems in a single machine
- Examples: VMWare, Virtualbox, ...

Virtual machines

Running apps on VMs

Requires guest operating system + libraries



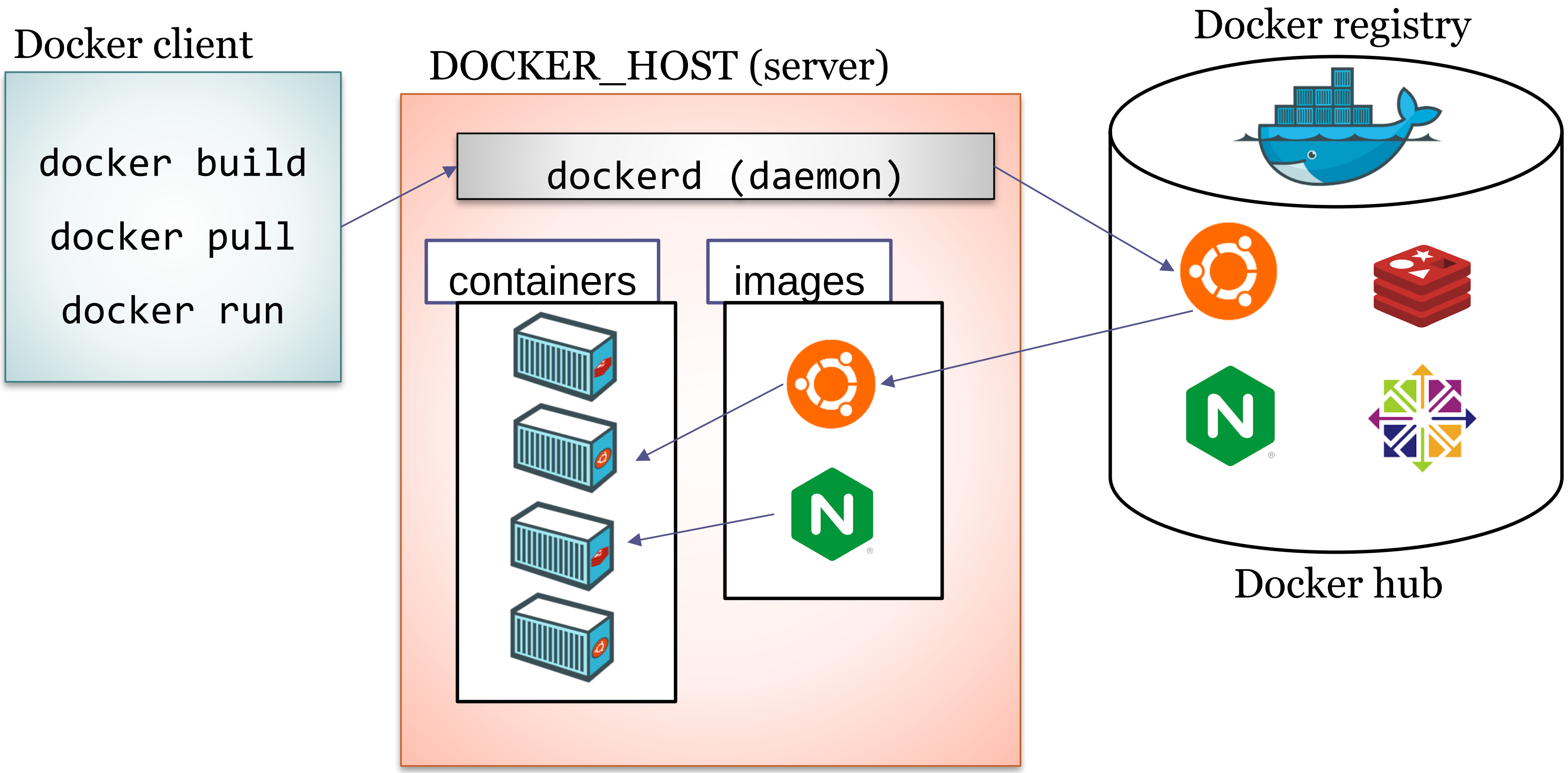
Advantages	Challenges
Portability	Resource consumption
Isolation	Startup times
Emulate whole machines	Less performance than bare-metal
	Can take a lot of space Each VM requires its own guest OS

Containers & docker

- Operating system level virtualization
  - Multiple isolated servers run on a single server
  - The same OS kernel implements the *guest* servers
    - Requires full process isolation at OS kernel
- Docker (started in 2011) supports containers
  - Several parts
    - Specification for container descriptions (images)
    - Platform that runs containers
    - Container registry (Docker-hub)

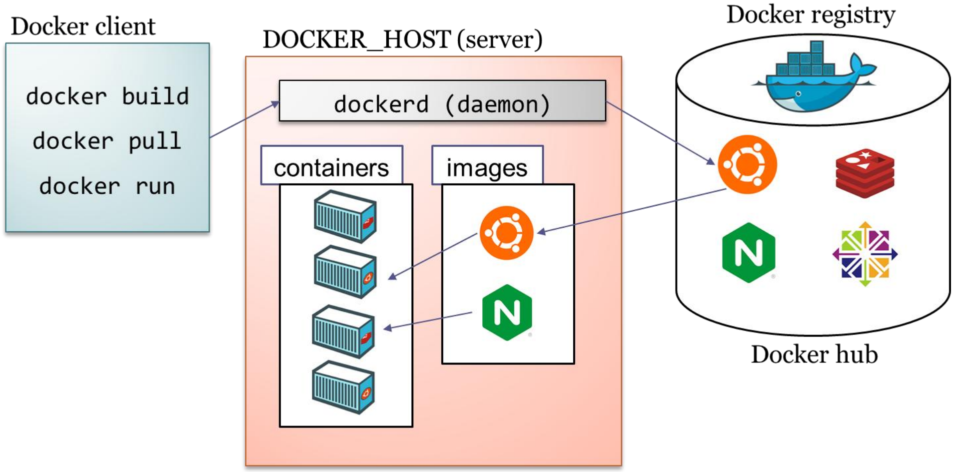
Docker high-level architecture

Client-server architecture



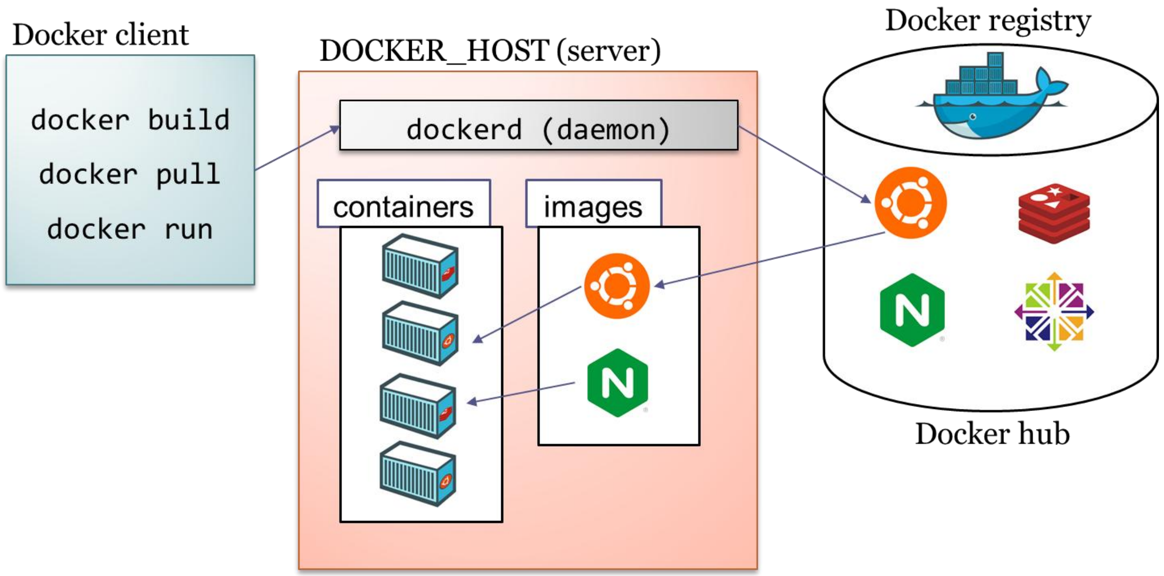
Docker images

- Container image = read-only template with instructions to create a running container
  - DSL language
  - Typically described in a *Dockerfile*
- Layered architecture
  - An image is usually *based on* another image + some customization
  - Each instruction creates a layer in the image
  - Lower layers can be reused



Docker containers

- A runnable instance of an image
- Containers are usually isolated
  - From other containers
  - From the host machine
- It is possible to configure isolation
  - Data volumes, network, ...

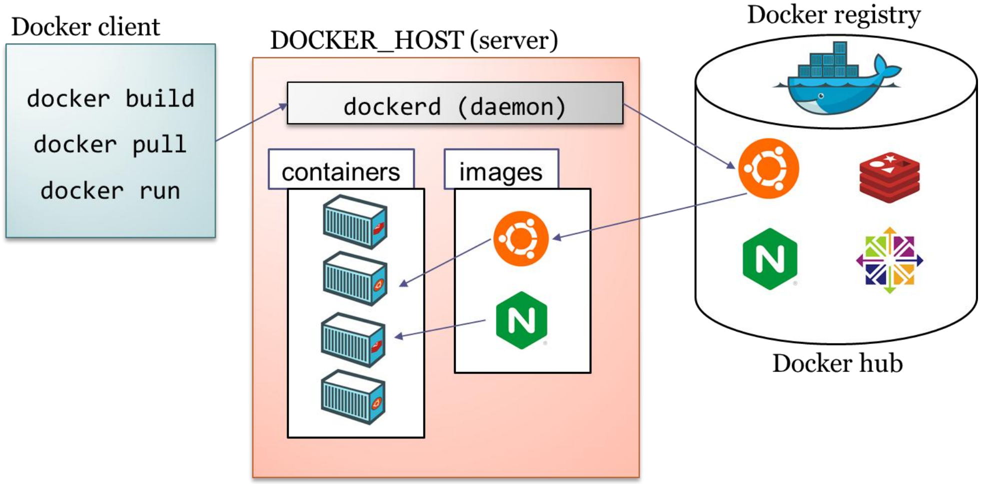


Docker registry

A Database of container images

Docker Hub is a public registry (used by default)

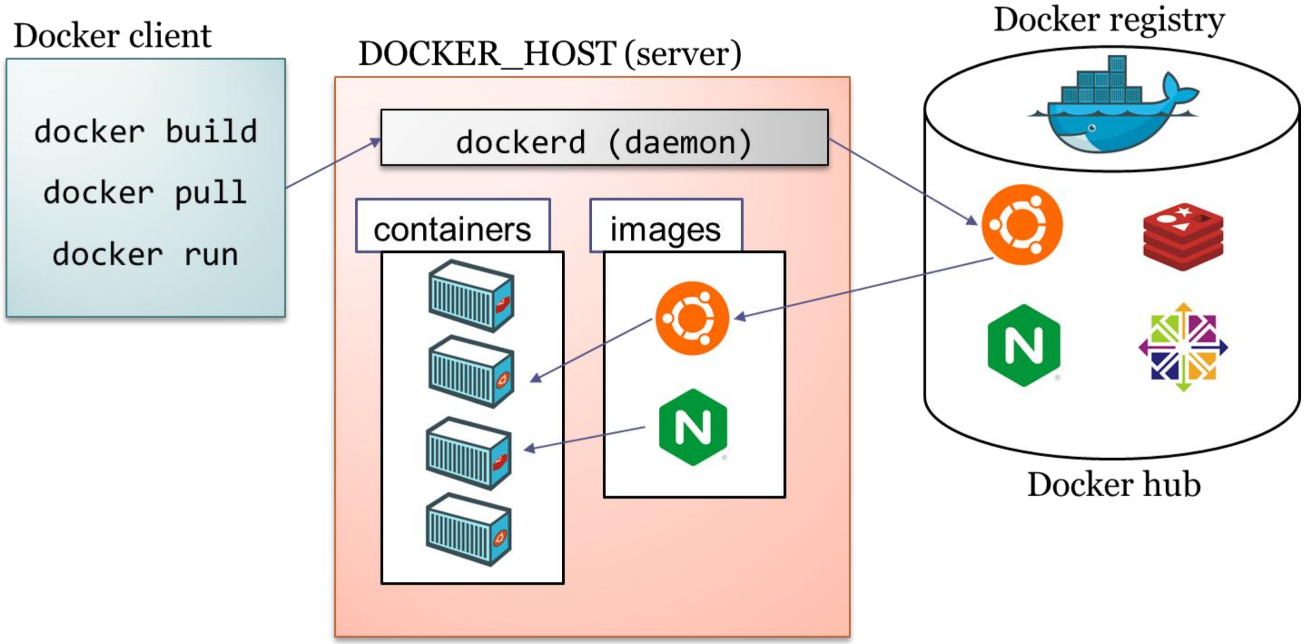
It is possible to use private registries



Docker client

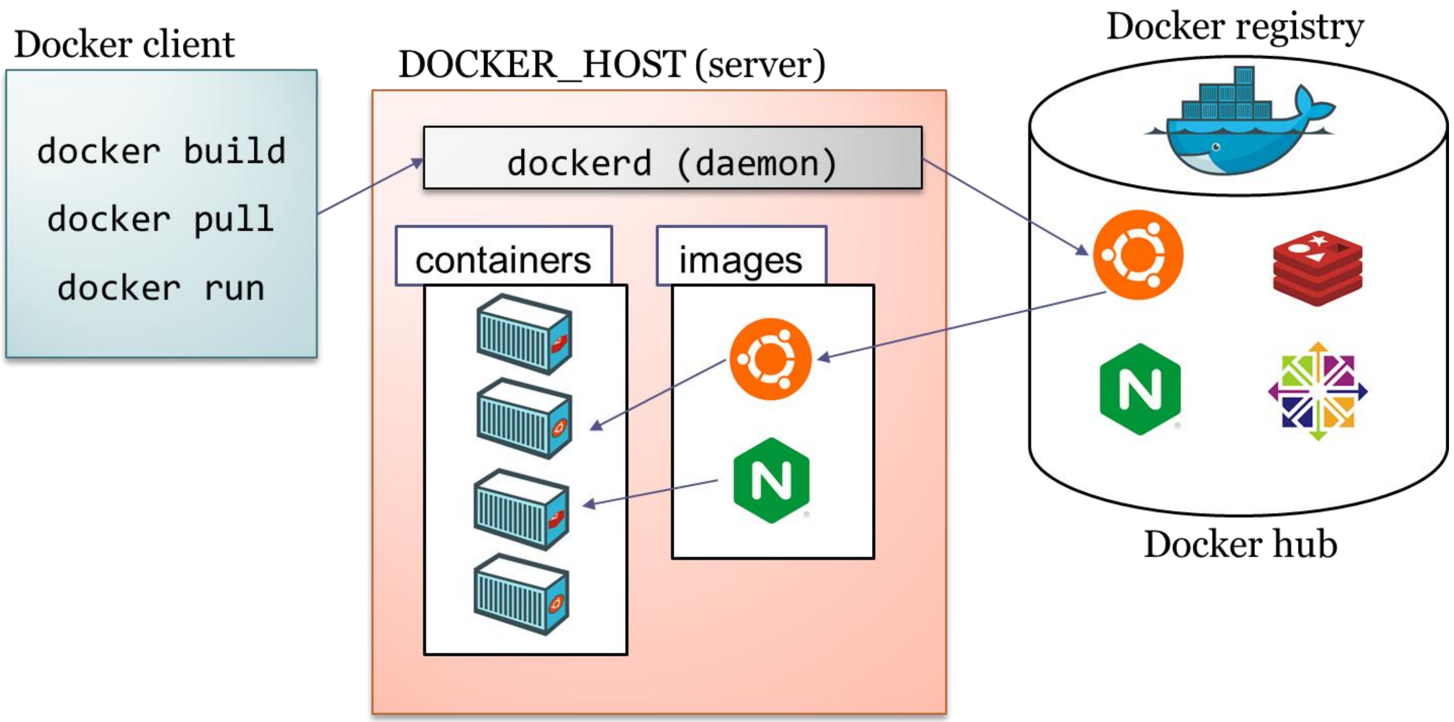
`docker` command

- Communicates with the docker daemon using the API
- Typical commands: docker pull, docker run, ...



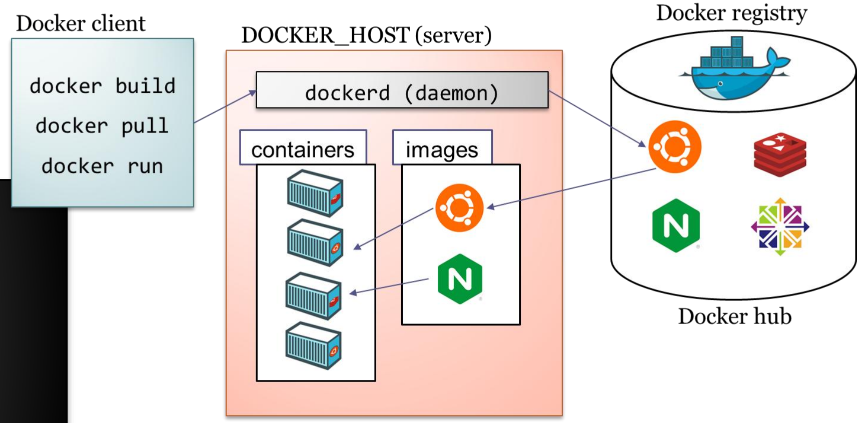
Docker daemon

- The docker daemon (`dockerd`) listens to API requests manages images and containers
  - It can also communicate with other daemons

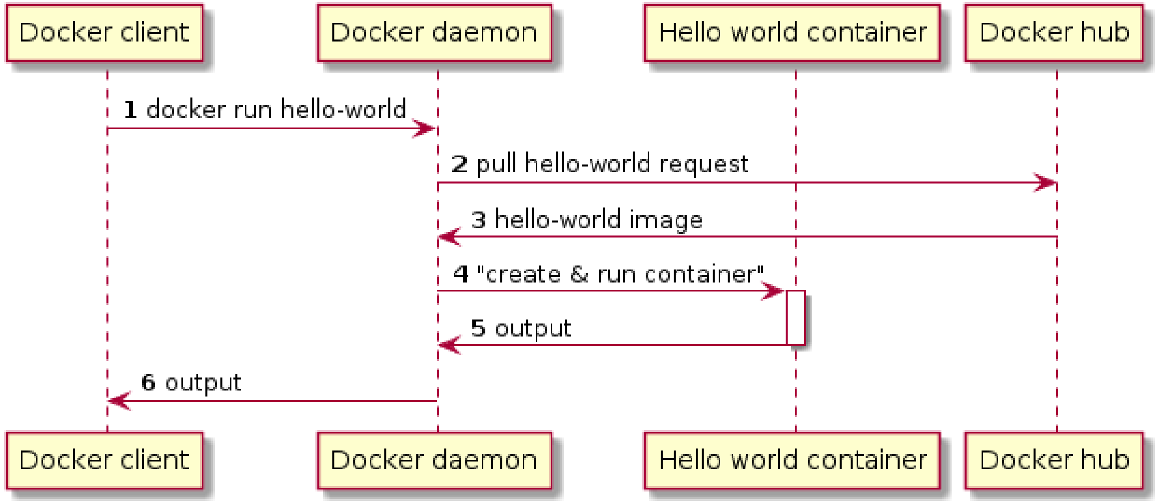


Docker example

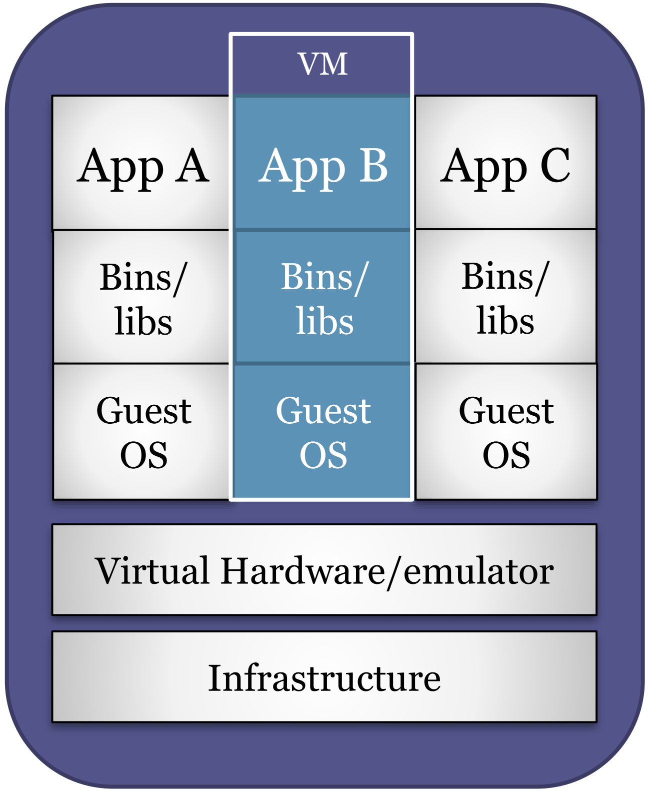
Sequence diagram for hello-world example

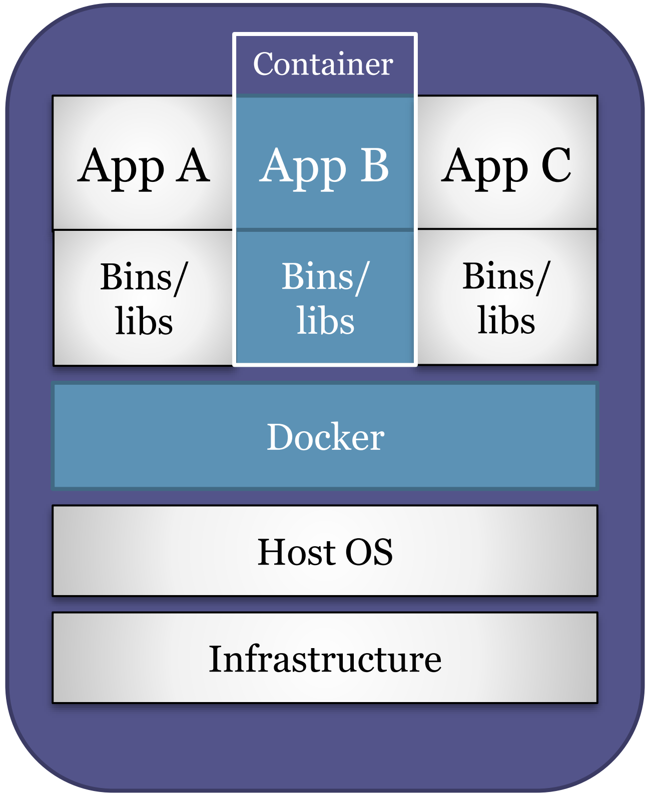


```
$ docker run hello-world
Unable to find image 'hello-world:latest' locally
latest: Pulling from library/hello-world
1b930d010525: Pull complete
Digest: sha256:f9dfddf63636d84ef479d645ab5885156ae030f...
Status: Downloaded newer image for hello-world:latest
```



Virtual machines vs Containers





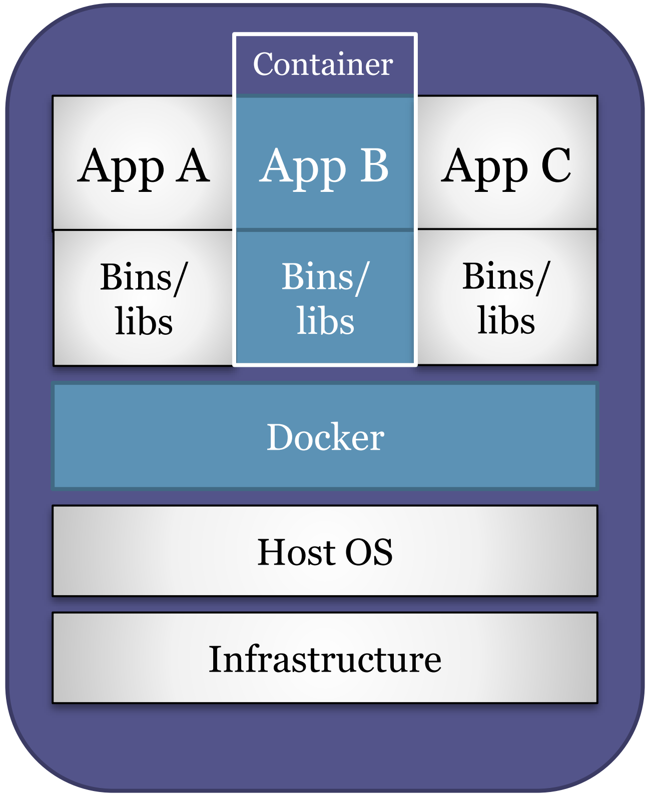
Containers consequences

Advantages

- Consistency & portability
- Easy to deploy
- Isolation
- Performance
  - Less space than VMs
  - 1000s of containers
- Immutable arcchitecture
  - Declarative configuration
  - Infrastructure as code
- Automation

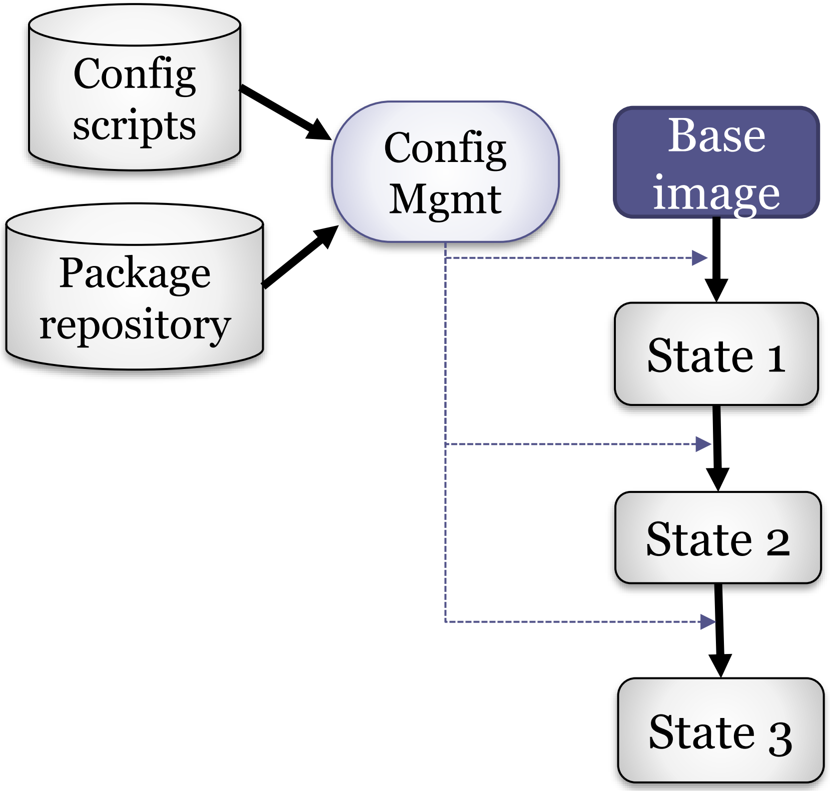
Challenges

- Orchestration
- Persistence more complex
- Graphical applications
- Platform-dependent (Linux)

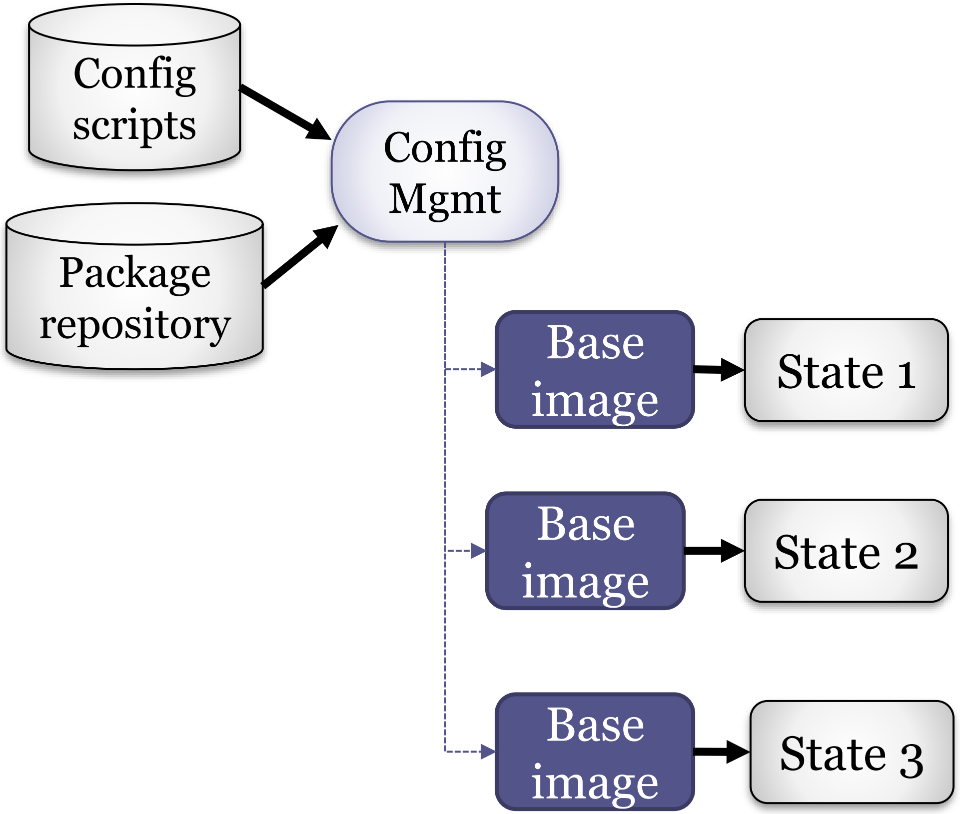


Mutable vs Immutable infrastructure

Mutable infrastructure



Immutable infrastructure



Container management

- Docker-compose = tool to define and run multi-container apps
  - YAML configuration file (docker-compose.yml)
- With a single command, create and start all the services from a multi-container configuration
- Docker-compose usually works in a single host

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Container orchestration

- Automatically manage clusters of containers
  - Typical features:
    - Load balancing, Container lifecycles, provisioning...
- Kubernetes
  - Initially developed by Google, donated to CNCF
  - Framework for distributed systems
  - Clusters consists of pods, deployments and services
  - Available in most cloud providers
- Docker swarm
  - Developed by Docker
  - It can be considered a "mode" of running docker

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Deployment

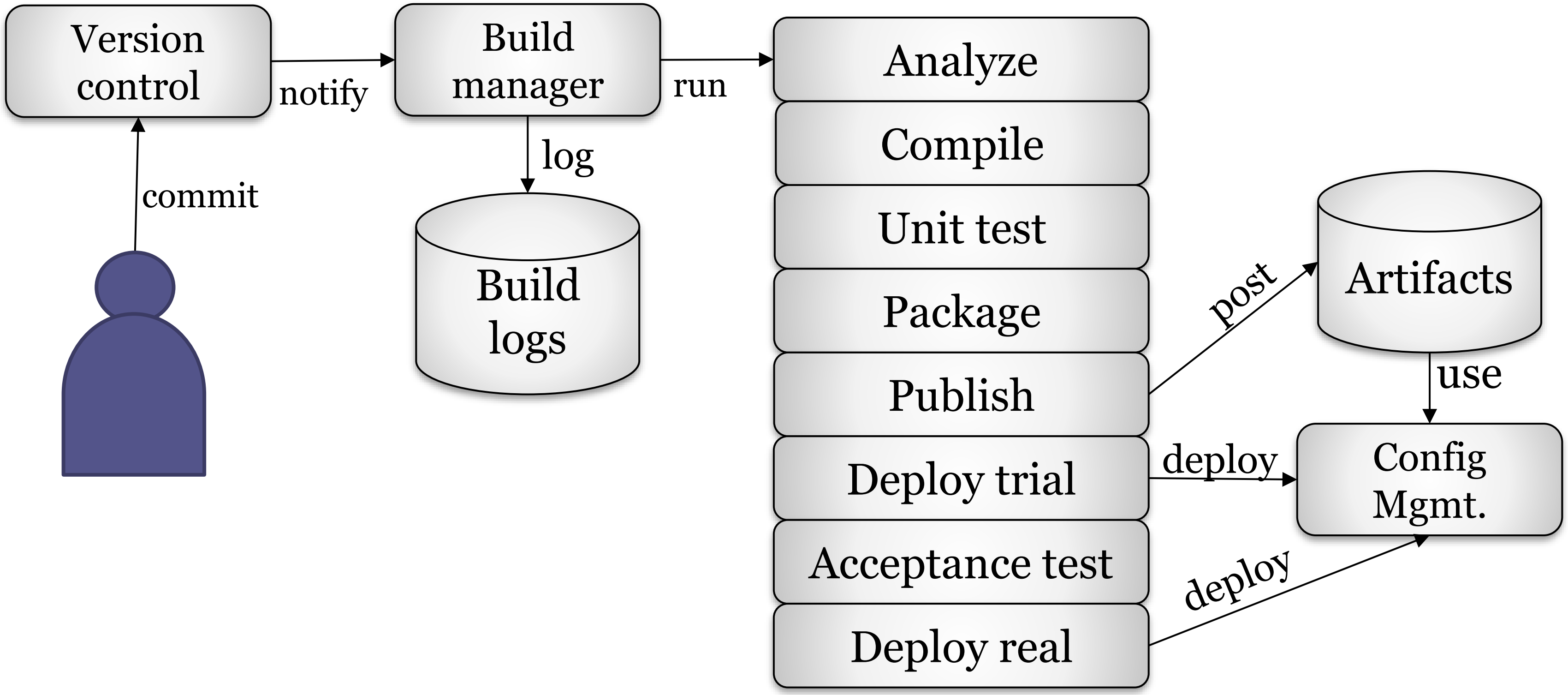
Deployment pipeline

Automated implementation of an application’s build, deploy, test and release process

Goals

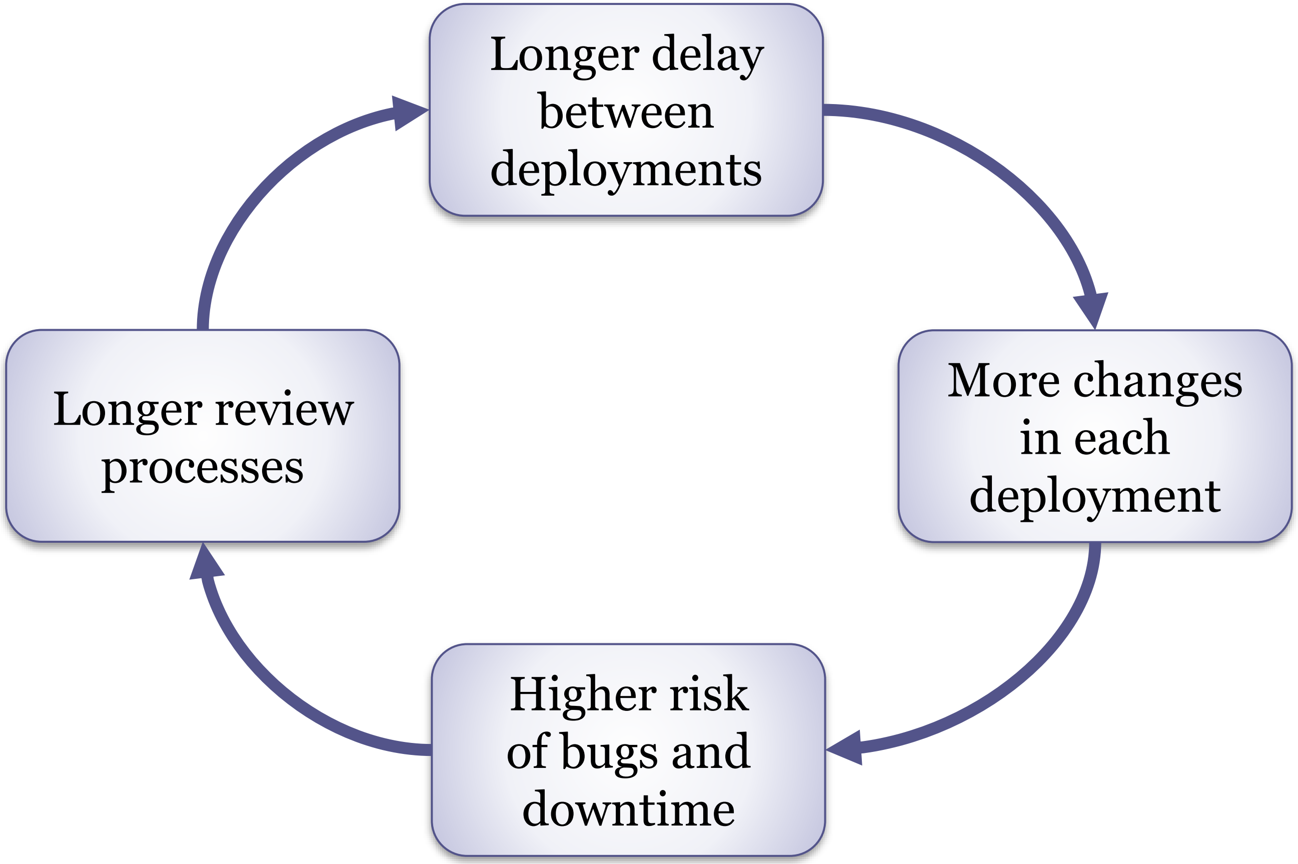
- *Create runtime environments on demand*
- *Fast, reliable, repeatable and predictable outcomes*
- *Consistent environments in staging and production*
- *Establish fast feedback loops to react upon*
- *Make release days riskless, almost boring*

Deployment pipeline



Manual deployment

Vicious circle of deployment size and risk



Longer delay between deployments

More changes in each deployment

Higher risk of bugs and downtime

Longer review processes

Continuous deployment

"If it hurts do it more often"

In the limit: "Do everything continuously"

Run the full pipeline in every commit

Final stage: deployment in production

- Possibilities
  - Confirmation by some human before going to production
  - Automatic deployment to production
  - Deployment to production marked by some tags
- Trade-off
  - Cost of moving slower vs cost of error in deployment

Continuous deployment

- Patterns
  - Infrastructure as code
  - Keep everything in Version Control
    - Code
    - Configuration
    - Data
  - Align development and operations (DevOps)
- Tools:
  - Ansible, Chef, Puppet,…
- Best practices: 12 factors (next slide)

12 factor https://12factor.net/

- **I. Codebase** One codebase tracked in revision control, many deploys
- **II. Dependencies** Explicitly declare and isolate dependencies
- **III. Config** Store config in the environment
- **IV. Backing services** Treat backing services as attached resources
- **V. Build, release, run** Strictly separate build and run stages
- **VI. Processes** Execute the app as one or more stateless processes
- **VII. Port binding** Export services via port binding
- **VIII. Concurrency** Scale out via the process model
- **IX. Disposability** Maximize robustness with fast startup and graceful shutdown
- **X. Dev/prod parity** Keep development, staging, and production as similar as possible
- **XI. Logs** Treat logs as event streams
- **XII. Admin processes** Run admin/management tasks as one-off processes

Software in production

Quality attributes in production

- Configurability
  - Customize system without re-compiling it
- Observability
  - Possibility to monitor the internal state of a system
- Availability
  - Probability that a system is working at time t
- Stability
  - Produce availability despite faults and errors
- Reliability
  - Probability that a system produces correct outputs over some time *t*

Configurability

- Lots of configurable properties
  - Hostnames, port numbers, filesystem locations, ID numbers, usernames, passwords, etc.
- Config files = interface between developers and operators
  - Should be human-readable and machine processable
  - Examples: XML, JSON, YAML, ...
- Can contain sensitive information
  - Separated from source code

Logging

- Logging is ubiquitous and easy to generate
  - White-box technology (integrated in source code)
    - They show activity and can easily persist
    - Human-readable
- Log locations
  - Separate logs from source code
- Logging levels
  - Find a good balance for logging between too noisy/silent
  - Anything marked as "ERROR" or "SEVERE" should require action
  - Remember: disable debug logs in production

Monitoring

- Monitoring: Observe the behaviour at runtime while software is running
  - Time-series database systems
  - Time-series visualizations and dashboards
    - Prometheus, Graphite, Grafana, Datadog, Nagios, ...
  - Health checks
- Profiling: Measure performance of a software while it is running

Data in production

- High availability and data replication
- Ensure backup and restore
- Database schemas in control version
    - Change requests
    - Data migration
- Data purging
- Sensible data in production
    - Inaccessible to developers
    - Encrypted
    - . . .

System problems

Fault:

- Incorrect internal state (not necessarily observable)
- Initiated by some defect or injection

Error:

- Observable incorrect operation

Failure:

- Loss of availability. System unresponsive

Chain reactions

Law of large systems

Large systems exist in a state of continuous partial failure

Corollary:

- *"Everything is working"* is the anomaly

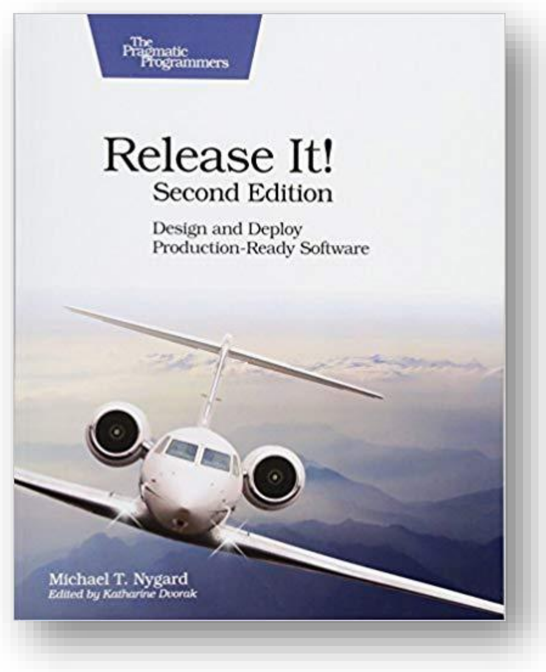
Important:

- Don't propagate faults

Source: "Airplane" film
https://www.imdb.com/title/tt0080339/

In-production patterns

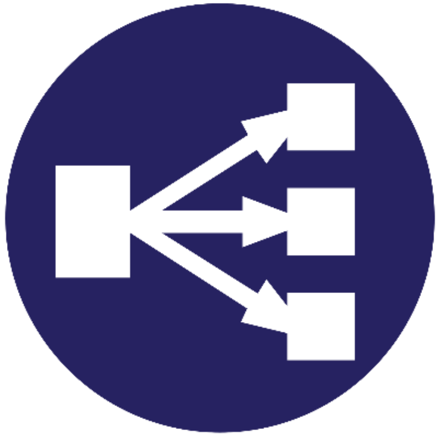
Load balancing
Timeouts
Circuit breakers
Bulkheads
Steady state
Fail fast
Handshaking
Test harnesses
Decoupling middleware
Create backpressure
Governor



Some libraries: https://resilience4j.readme.io/

Load balancing

- Distribute requests across a pool of instances
- Goal:
  - Serve all requests correctly in shortest feasible time
- Decisions to take:
  - Load balancing algorithms
  - What health checks to do on instances
  - What to do when no pool members are available
- Hardware/Software load balancers

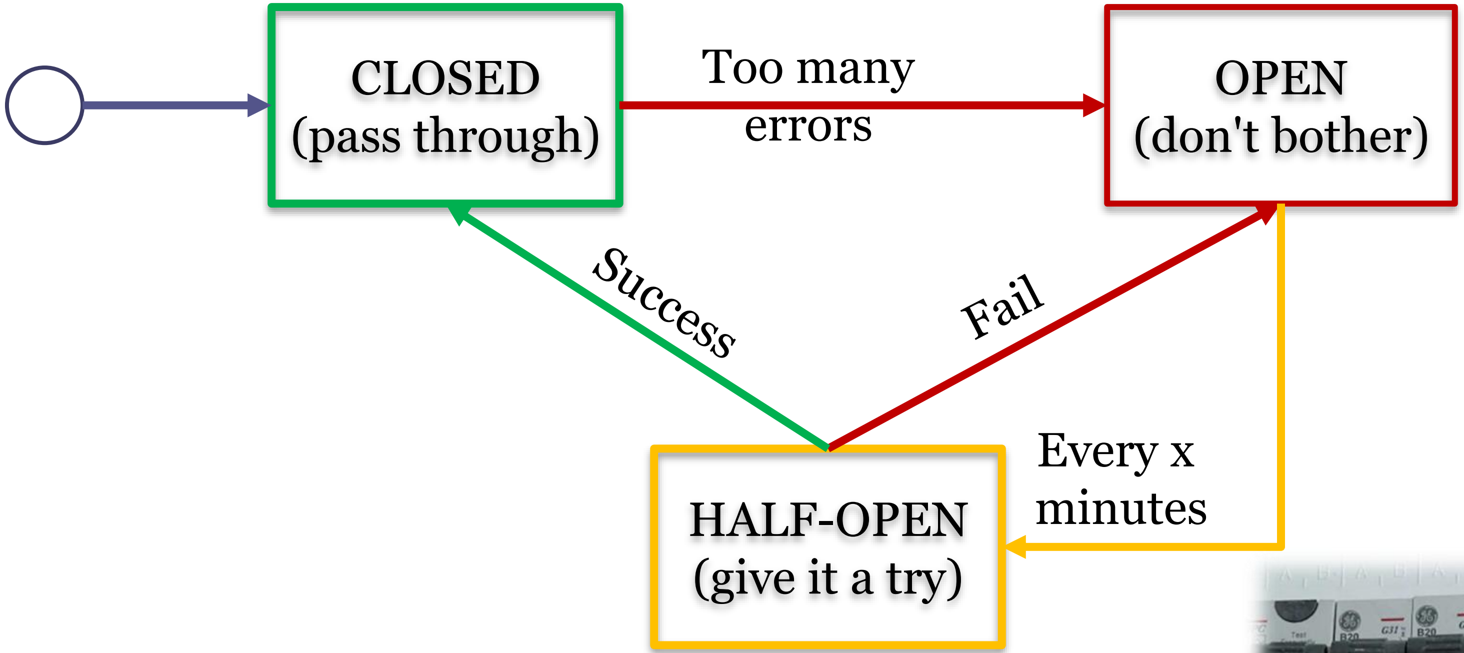


Timeouts

- Add a time limiter to other services requests
  - Provide fault isolation
    - A problem in some other service does not have to become your problem
- Timeouts usually followed by retries
  - It may make things worse
    - The situation may not recover automatically
    - The consumer waits more time
  - Sometimes, just failing is better

Circuit breaker

Inspired by electrical fuses



CLOSED
(pass through)

Too many errors

OPEN
(don't bother)

Success

Fail

Every x minutes

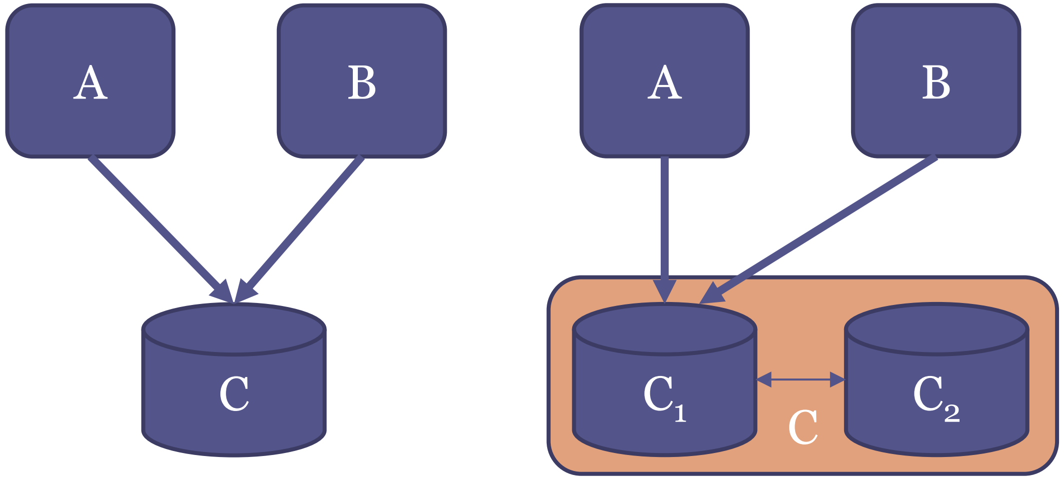
HALF-OPEN
(give it a try)

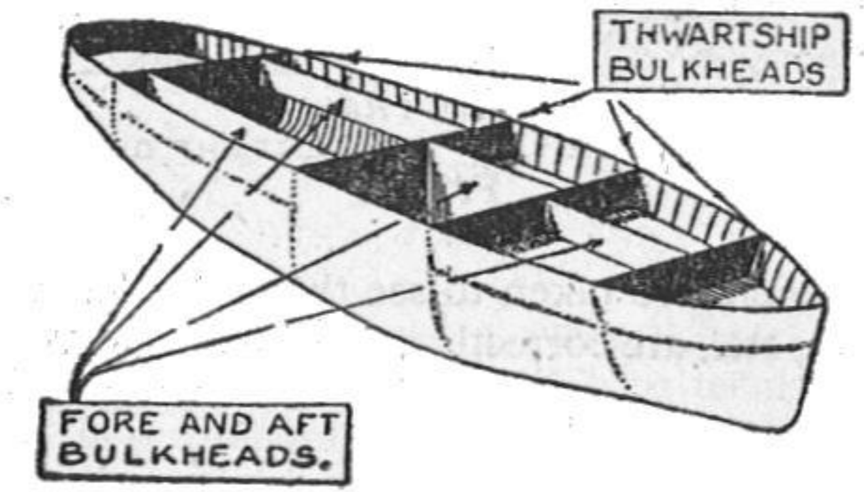
Bulkheads

"Contain damage" (save part of the ship)

If a component breaks, the system still works

Example: replicate instances in the cloud





Steady state

- *"Nothing is infinite"*
- Keep system resources constant
- Avoid human intervention for cleanup
- Examples:
  - Data purging
  - Log files
  - In-memory caching

Fail fast

- Don't make consumers wait for a failure response
  - Reserve resources before starting work
  - Don't do useless work
  - Verify integration points early
  - Check all resources are available before start
  - Basic input validation
- Shed load
  - Refuse new requests when load is too high

"Check ingredients before cooking"

Let it crash

- "Crash components to save systems"
- Inspired by Erlang's error handling
    - If a component can't do what it has to do, let it crash
        - Let some other component do the recovery
        - Do not program defensively
- Conditions
    - Create boundaries
        - A component crashes in isolation
    - Fast replacement
    - Supervision
    - Reintegration

Handshaking

"Agree before doing"

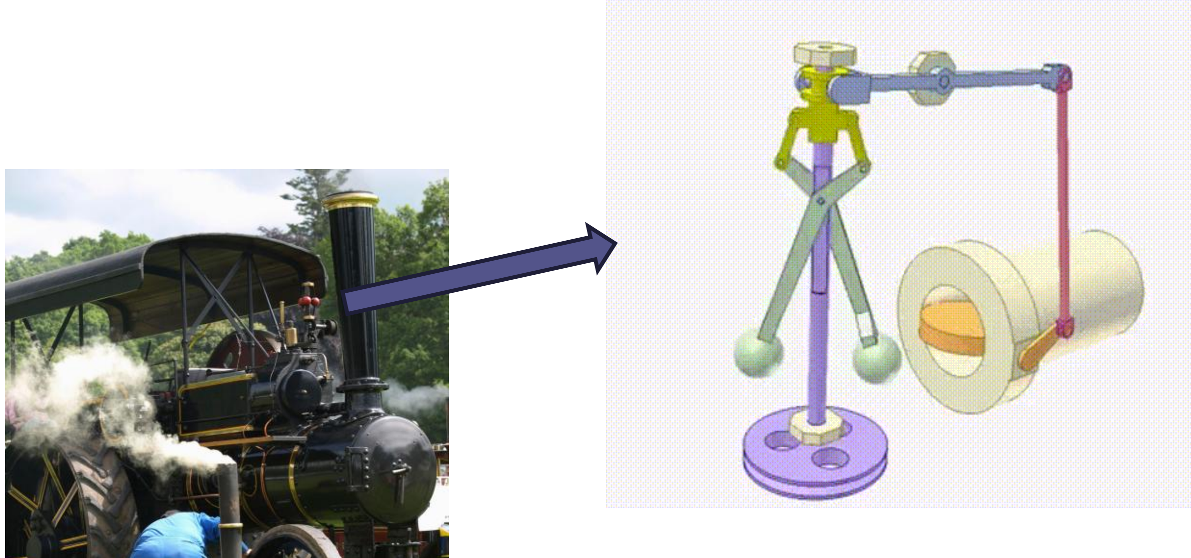
- Cooperative demand control
  - Both clients and servers agree
  - The server can reject incoming work
- Services provide "health check" query
  - Load balancers check health before directing a request to some instance

Create backpressure

- Backpressure = *resistance opposing desired flow of data*
- Input is coming faster than we can output
  - Create safety by slowing down producers
- Strategies
  - Control the producer (slow down producers)
  - Buffer (accumulate incoming data temporarily)
    - Unbounded buffers can be very dangerous
  - Drop
    - Not always acceptable to lose data

Governor

- Create governors to slow the rate of actions
  - When automation goes wrong, it can do bad things very quickly
  - Avoid force multiplier
- Slow things down to allow human intervention
- Apply resistance in the unsafe direction
  - Examples: shutdowns, deleting instances, ...
- Consider a response curve



Test harnesses

"Be evil when testing"

Create test harnesses that check most failure modes

Emulate out-of-spec failures

Stress the caller

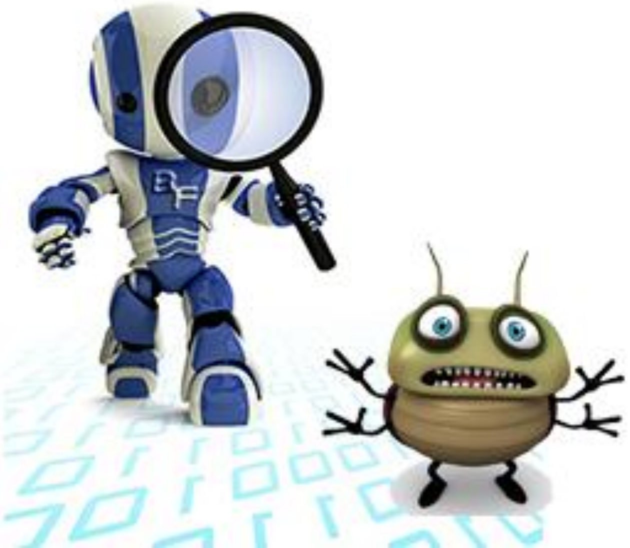
- Produce slow responses, no responses, garbage responses

Shared harnesses can be reused

- Example: killer services

Related with Chaos engineering

- [See later]



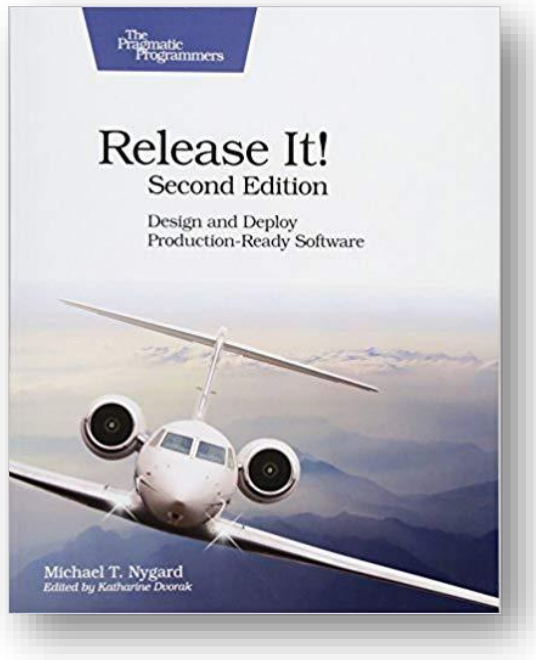
Chaos engineering

- Started by Netflix in 2010 (Chaos Monkey)
- Test distributed systems
  - Break things on purpose
    - Failure injection testing
    - Ensure that one instance failure doesn't affect the system
  - Antifragility and resilience

https://github.com/Netflix/chaosmonkey

In-production antipatterns

- Integration points
- Chain reactions
- Cascading failures
- Users
- Blocked threads
- Self-denial attacks
- Scaling effects
- Unbalanced capacities
- Dogpile
- Force multiplier
- Slow responses
- Unbounded result sets



Testing in production

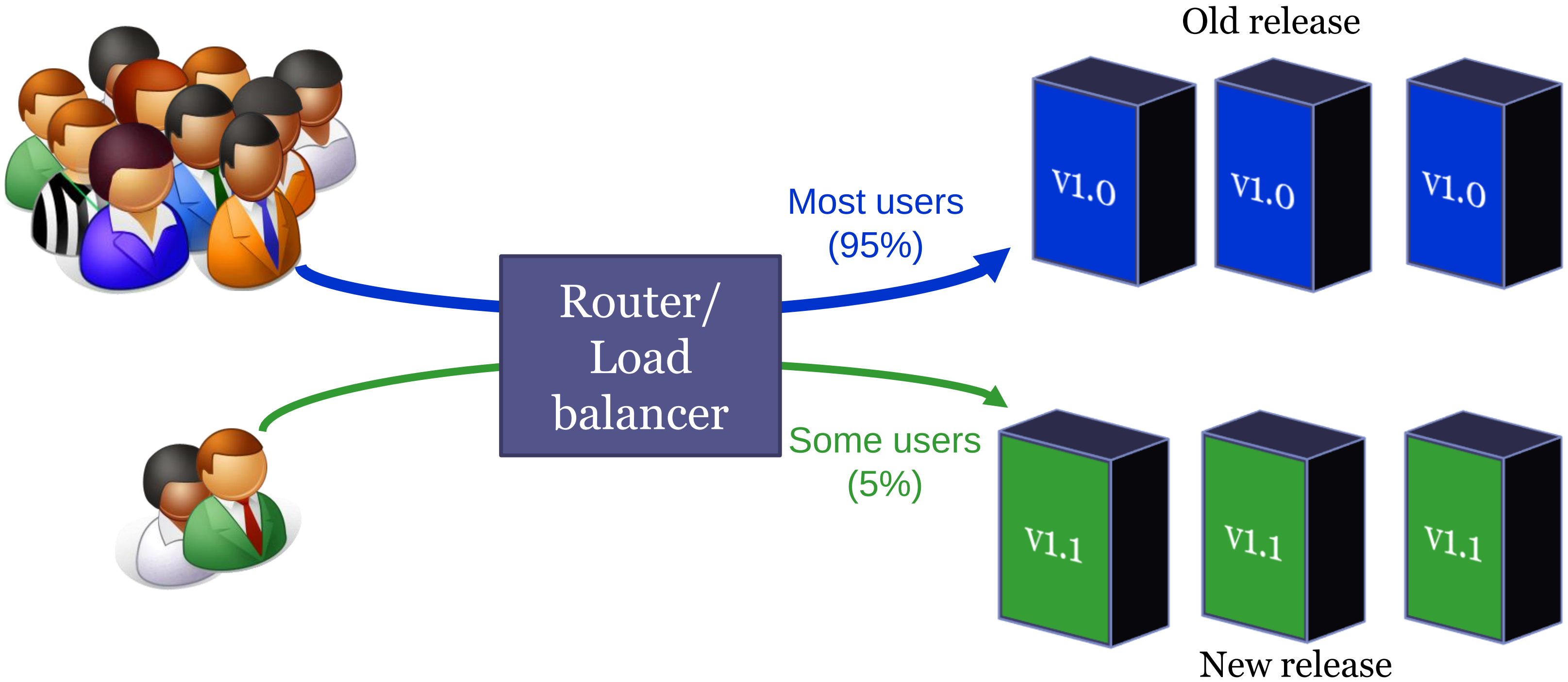
- Progressive delivery
  - Reduce *blast radius* of new deployments
  - Enable experimentation
- Some techniques
  - Canary releases
  - Feature toggles
  - A/B testing and multi-armed bandits

Blast radius of a deployment:
Who is impacted? What functionality? How many locations? ...

Canary release

Introduce new releases by slowly rolling out the change to small subset of users

- Infrastructure driven (router/load balancers)
- Blue-Green deployment



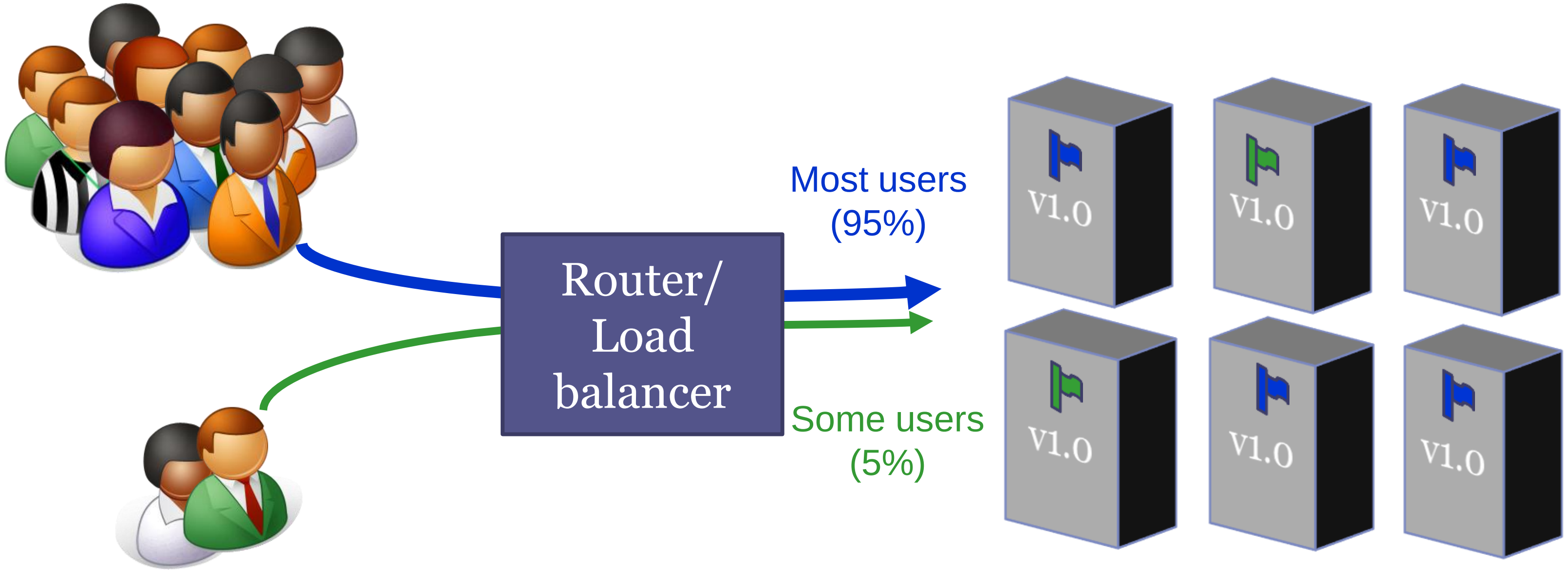
https://martinfowler.com/bliki/CanaryRelease.html

Feature toggles

Also known as *feature flags*, *feature bits*

Modify system behaviour without changing code

Decouple deployment from release

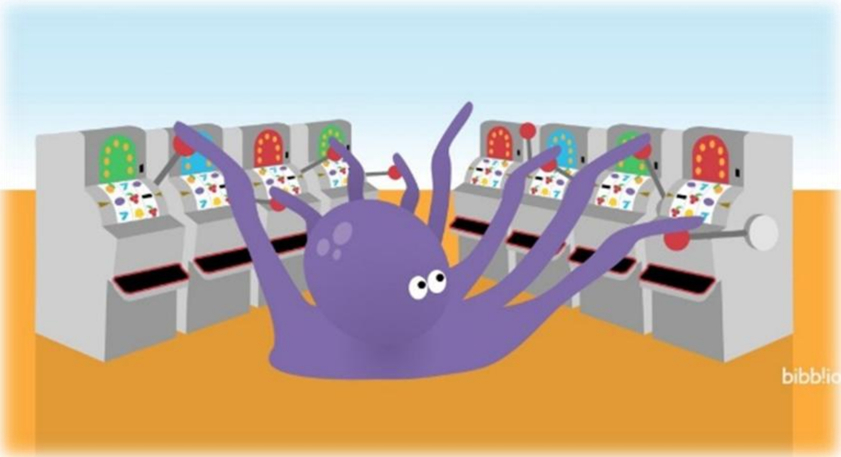


https://martinfowler.com/articles/feature-toggles.html

Types of tests

A/B testing:
- Also known as split testing, bucket testing
- Controlled experiment to test some hypothesis
- Divide users in groups
  - Problem: Bad alternatives shown to groups of users during experiment

Multi-armed bandits
- Dynamic traffic allocation
- Bad alternatives get less users during time

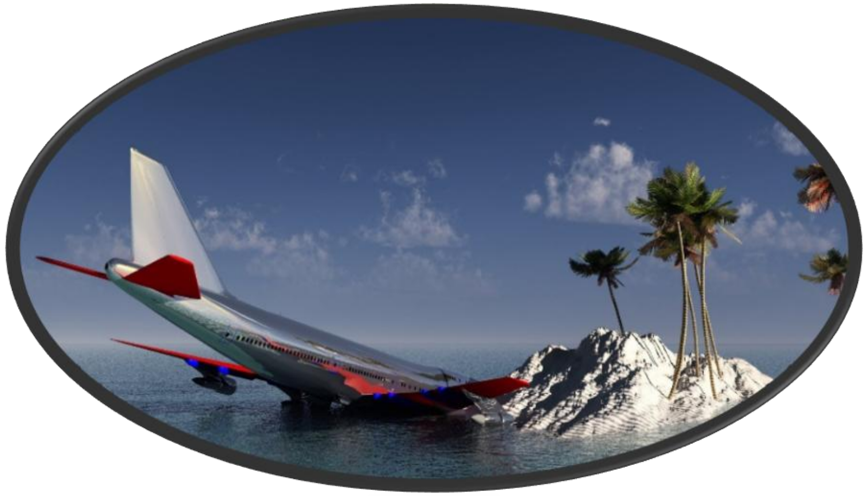


Load & stress testing

- Load testing
  - Test performance under load
  - Example: simulate multiple users accessing concurrently
- Stress testing
  - Load raised beyond normal usage patterns to test system's response
  - Check upper bounds
    - What happens when limit is reached
- Several tools
  - JMeter, Gatling

Incidents & post-mortem

- Resolve and review incident
- Ensure team view it as **blameless**
- Create post-mortem report
  - Incident details
  - Root Cause Analysis
  - Timeline and actions taken to resolve it
- Identify preventive measures



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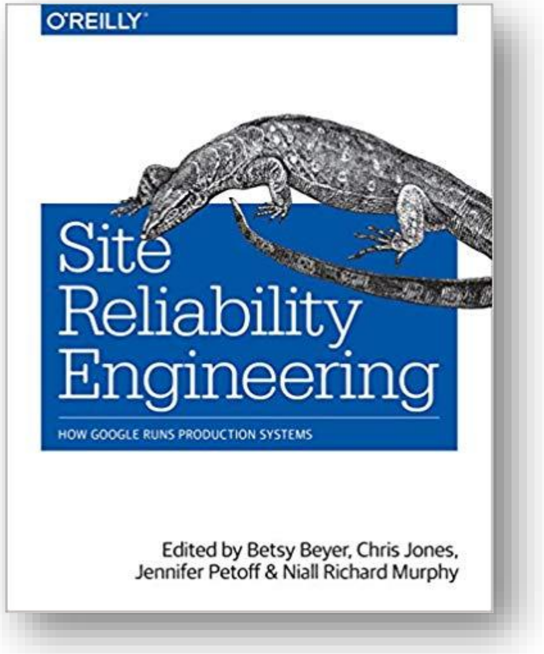
End of presentation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