CS 4530 Software Engineering

Module 14: Principles and Patterns of Cloud Infrastructure

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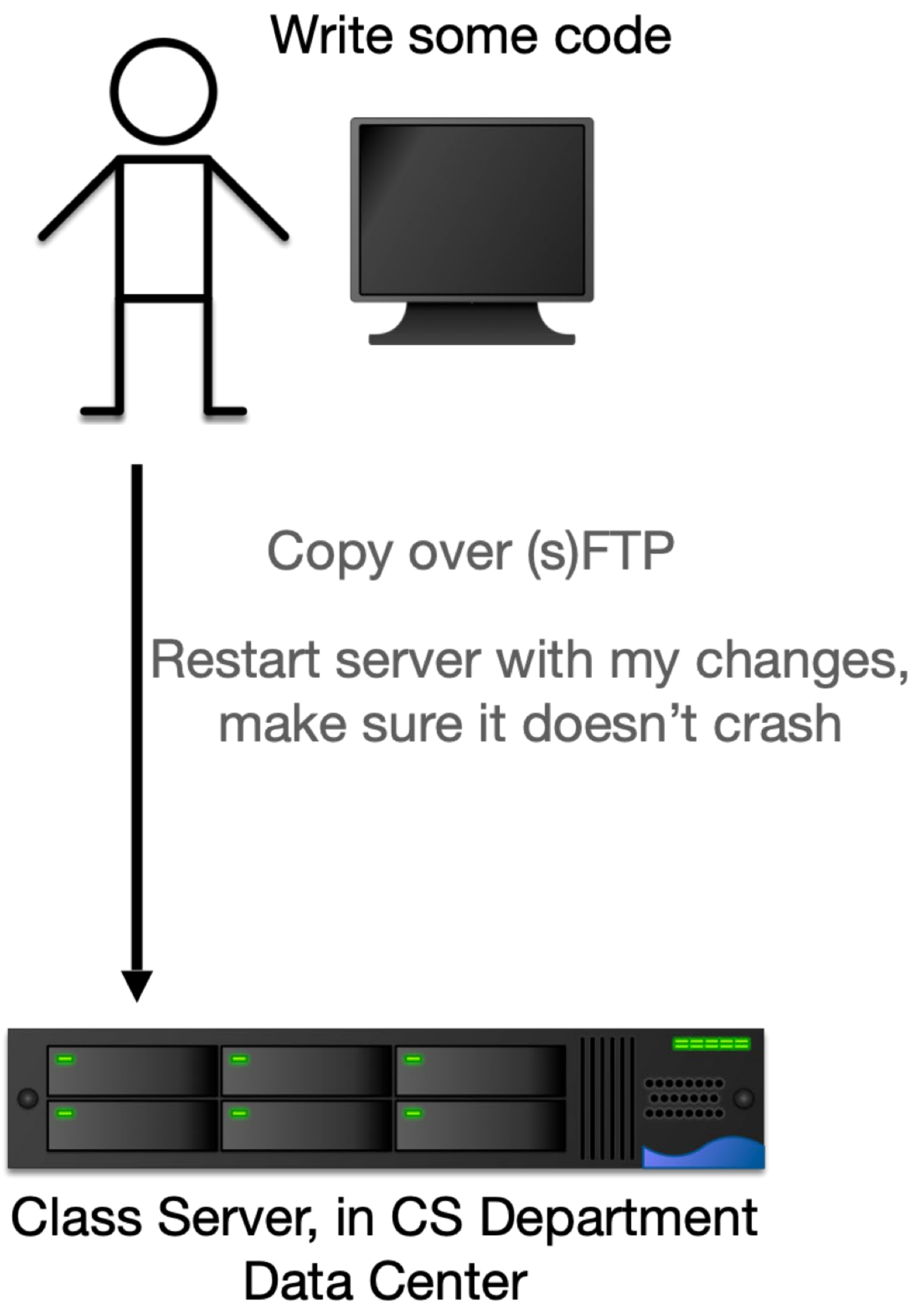
Learning objectives for this lesson

- By the end of this lesson, you should be able to…
  - Explain what “cloud” computing is and why it is important
  - Explain why shared infrastructure is important in cloud computing
  - Describe the difference between virtual machines and containers
  - Discuss trade-offs that you might consider for self or vendor-managed platforms

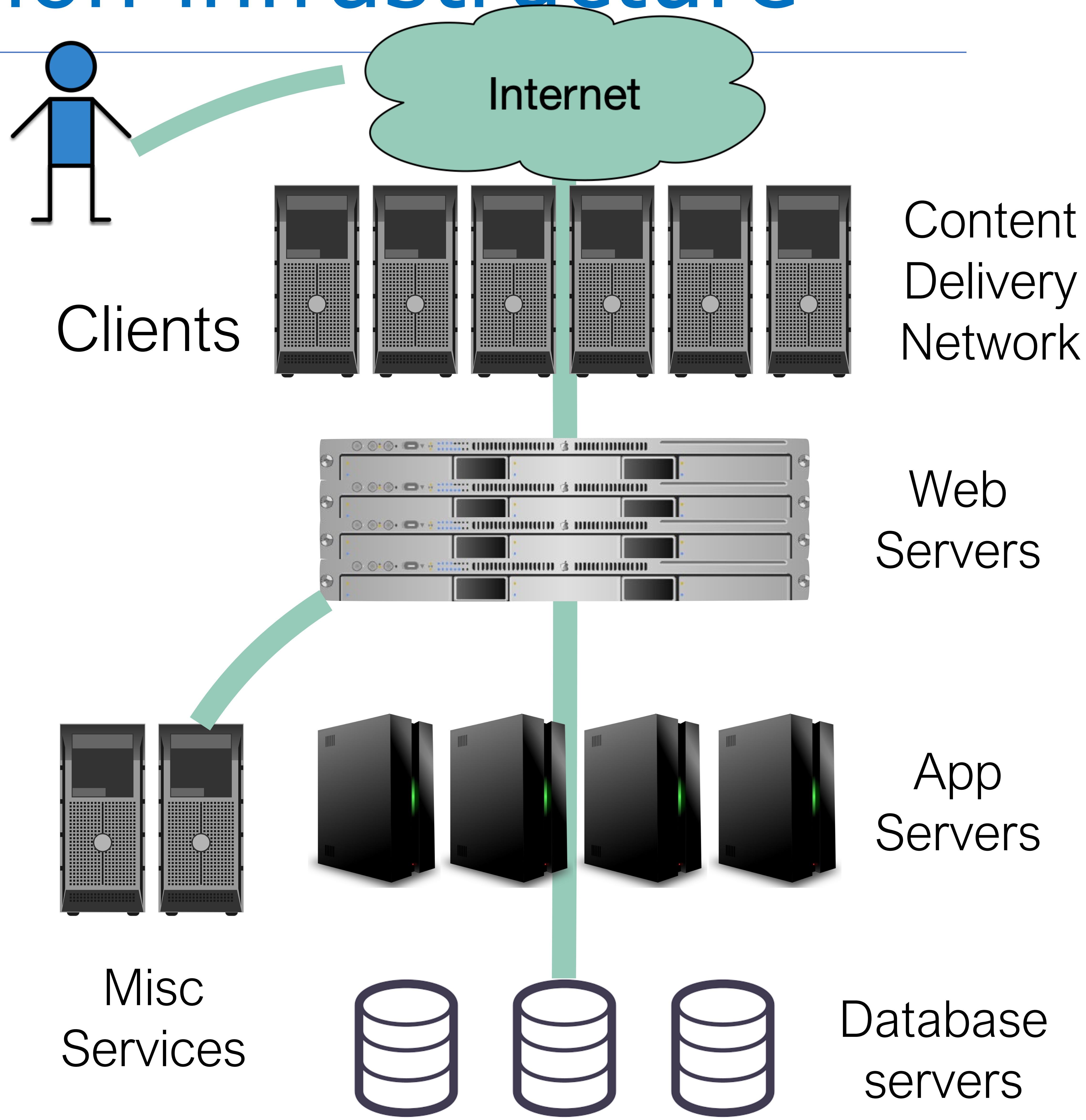
How to deploy web apps?

- What we need:
  - A server that can run our application
  - A network that is configured to route requests from an address to that server
- Questions to think about:
  - What software do we need to run besides our application code? (Databases, caches, etc?)
  - Where does this server come from? (Buy/Borrow?)
  - Who else gets to use this server? (Multi-tenancy or exclusive?)
  - Who maintains the server and software? (Updates OS, libraries, etc?)



Many apps rely on common infrastructure

- Content delivery network: caches static content “at the edge” (e.g. cloudflare, Akamai)
- Web servers: Speak HTTP, serve static content (eg REACT), load balance between app servers (e.g. haproxy, traefik)
- App servers: Run our backend application (e.g. nodejs)
- Misc services: Logging, monitoring, firewall
- Database servers: Persistent data



Render.com terminology

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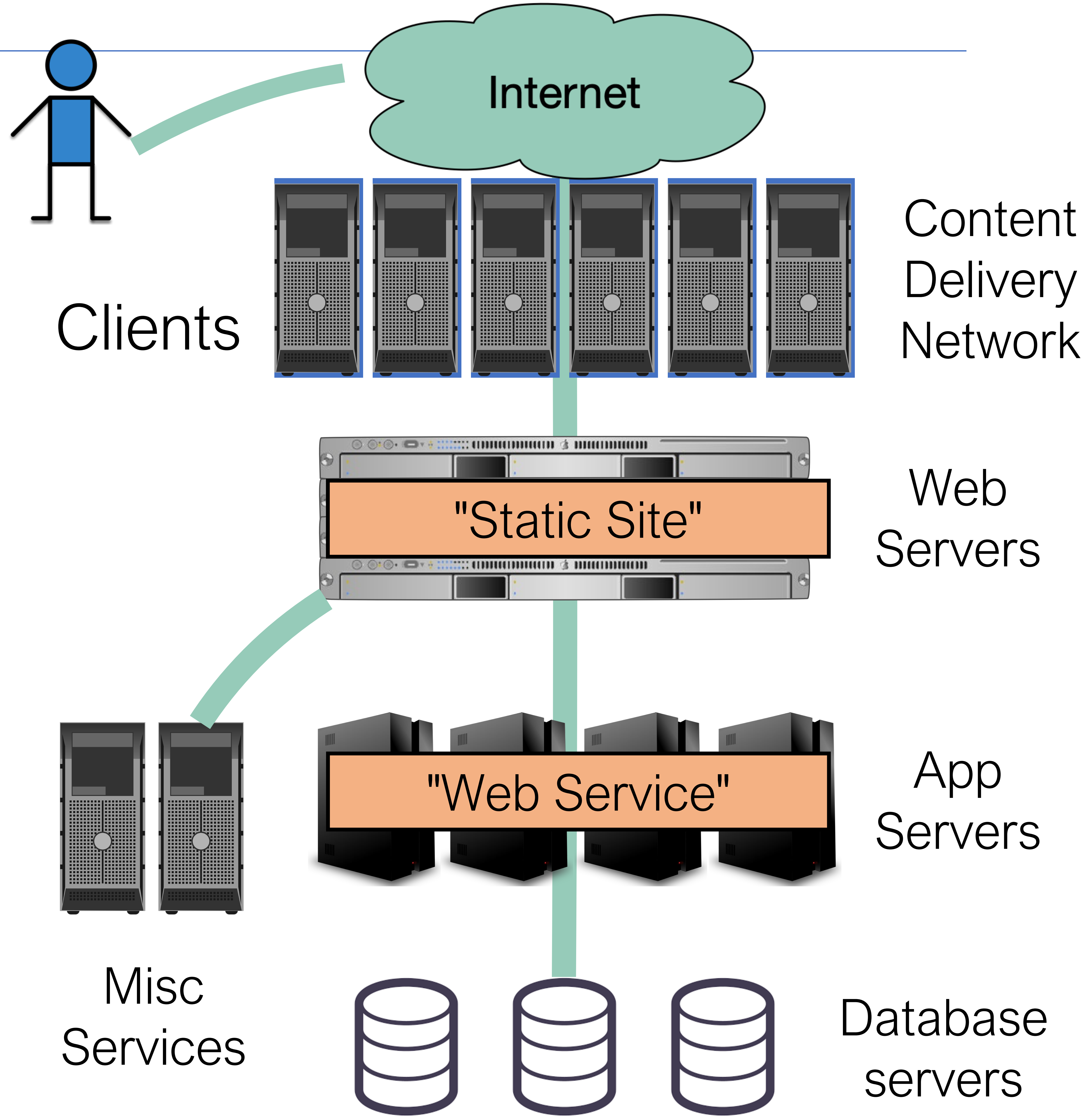
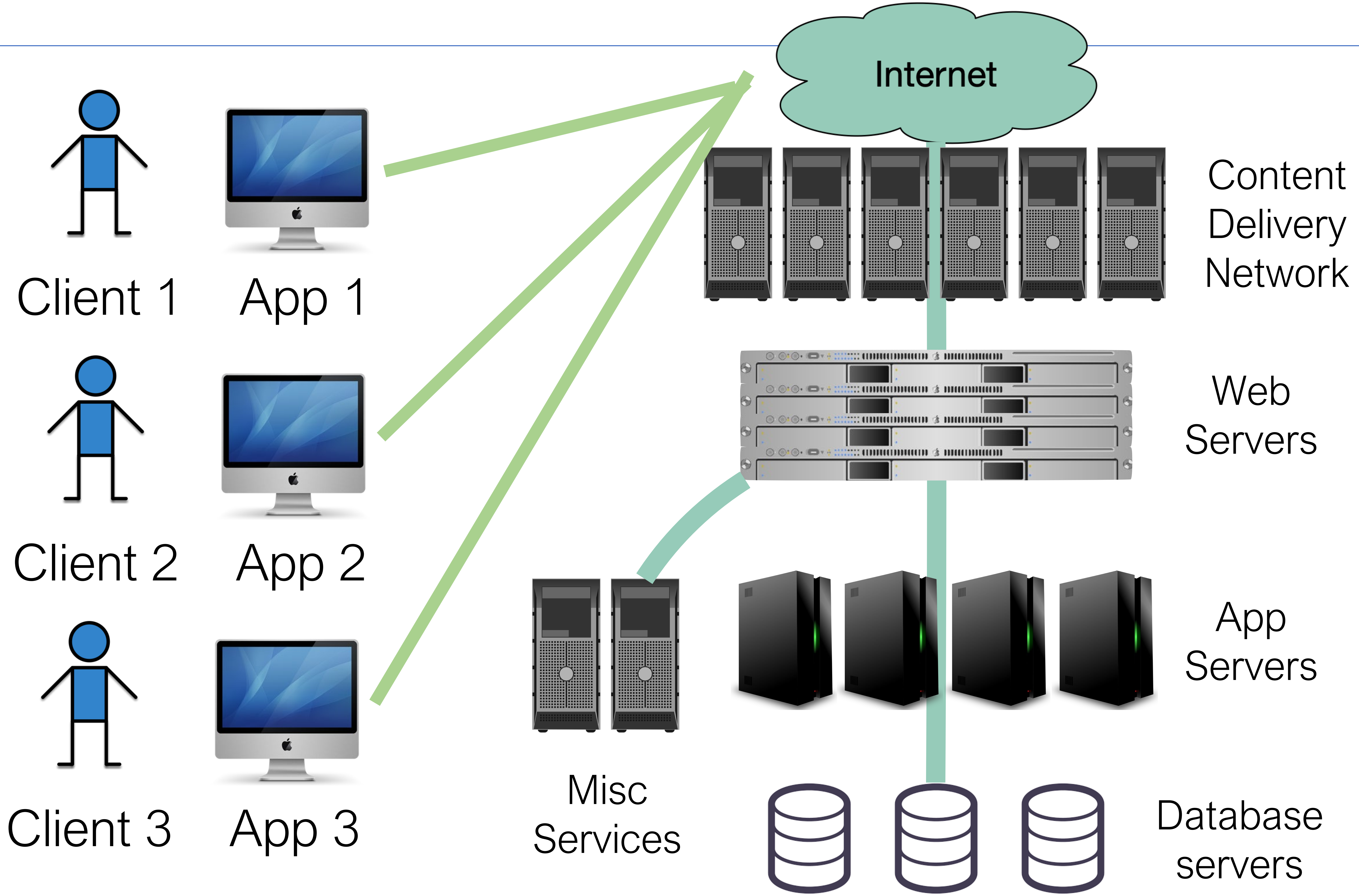
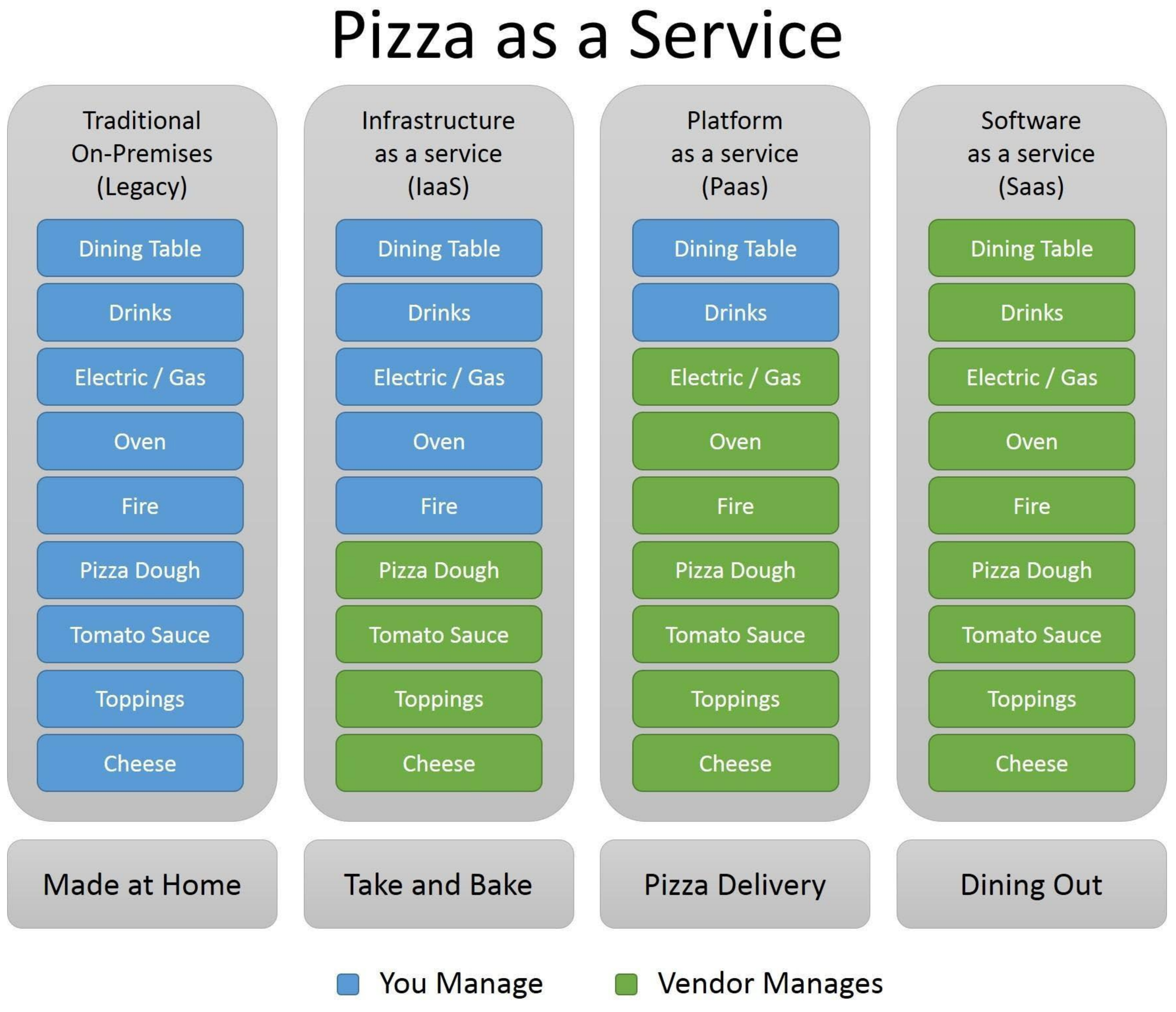


What parts of this infrastructure can be shared across different clients?



Shared infrastructure analogy: Pizza

- Four ways to get pizza: Make yourself, take and bake, delivery, dine out
- Vendor manages different levels of the stack, achieving economies of scale
- When would you choose one over the other?



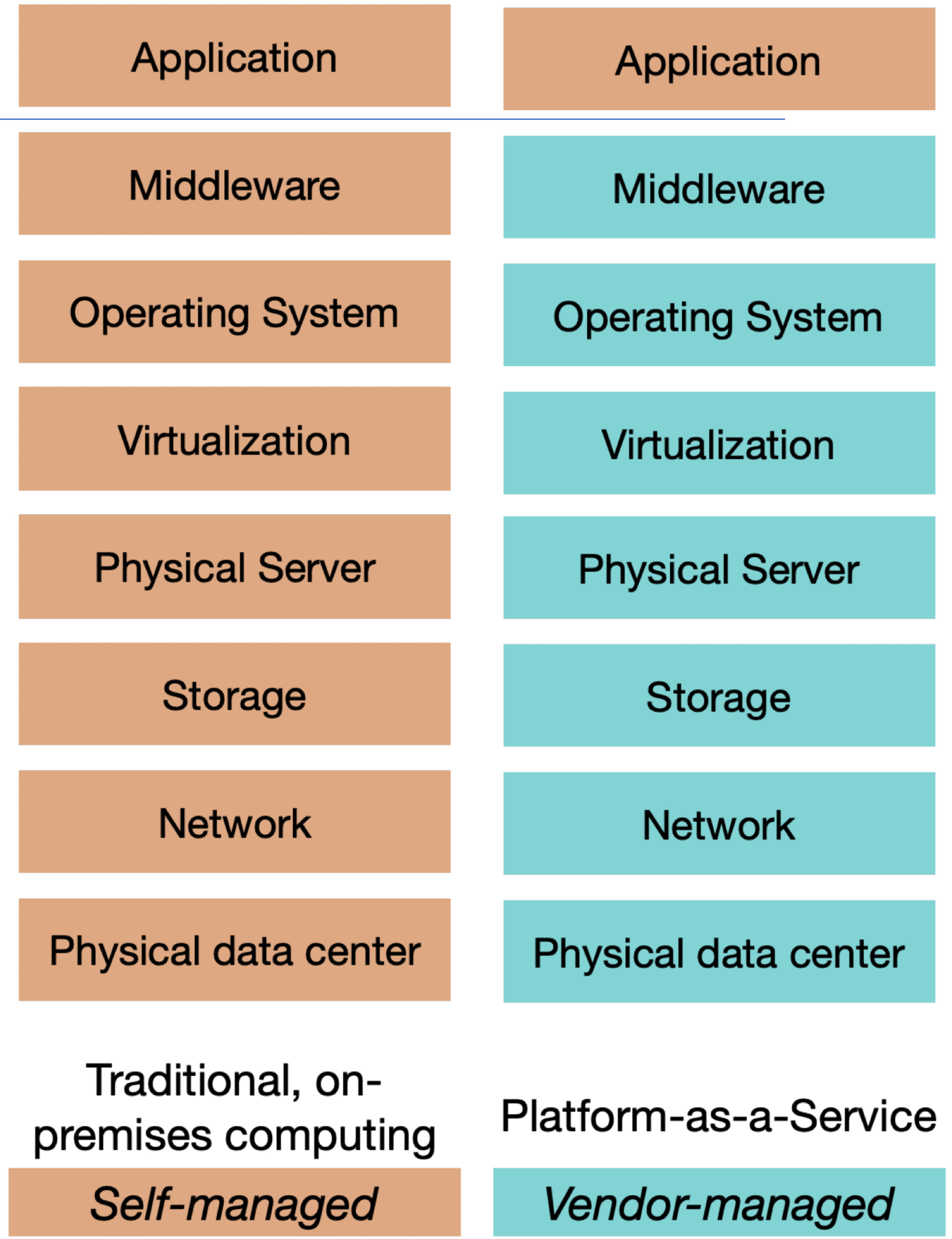
Pizza as a Service — by Albert Barron (unlicensed?)

Shared infrastructure creates economies of scale

- At the physical level:
  - Multiple customers’ physical machines in the same data center
  - Save on physical costs (centralize power, cooling, security, maintenance)
- At the physical server level:
  - Multiple customers’ virtual machines in the same physical machine
  - Save on resource costs (utilize marginal computing capacity – CPUs, RAM, disk)
- At the application level:
  - Multiple customer’s applications hosted in same virtual machine
  - Save on resource overhead (eliminate redundant infrastructure like OS)
- “Cloud” is the natural expansion of multi-tenancy at all levels

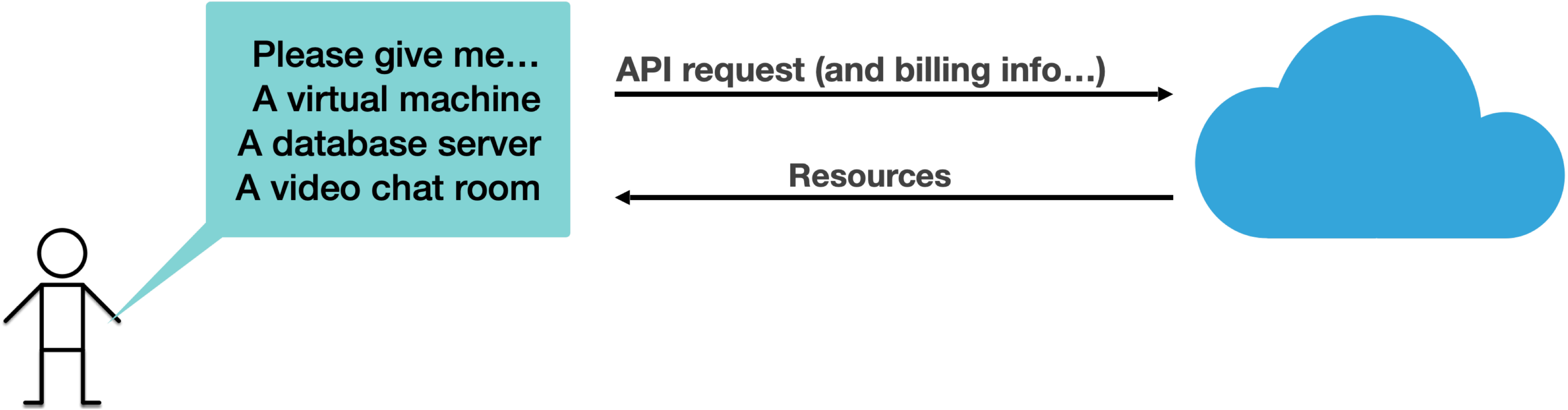
What is the infrastructure that can be shared?

- Our apps run on a "tall stack" of dependencies
- Old style: this full stack is self-managed
- Cloud providers offer products that manage parts of that stack for us:
  - "Infrastructure as a service"
  - "Platform as a service"
  - "Software as a Service"
  - Collectively called "X as a Service"



Cloud services gives on-demand access to infrastructure, "as a service"

- Vendor provides a service catalog of "**X as a service**" abstractions that provide infrastructure as a service
- API allows us to provision resources on-demand
- Transfers responsibility for managing the underlying infrastructure to a vendor

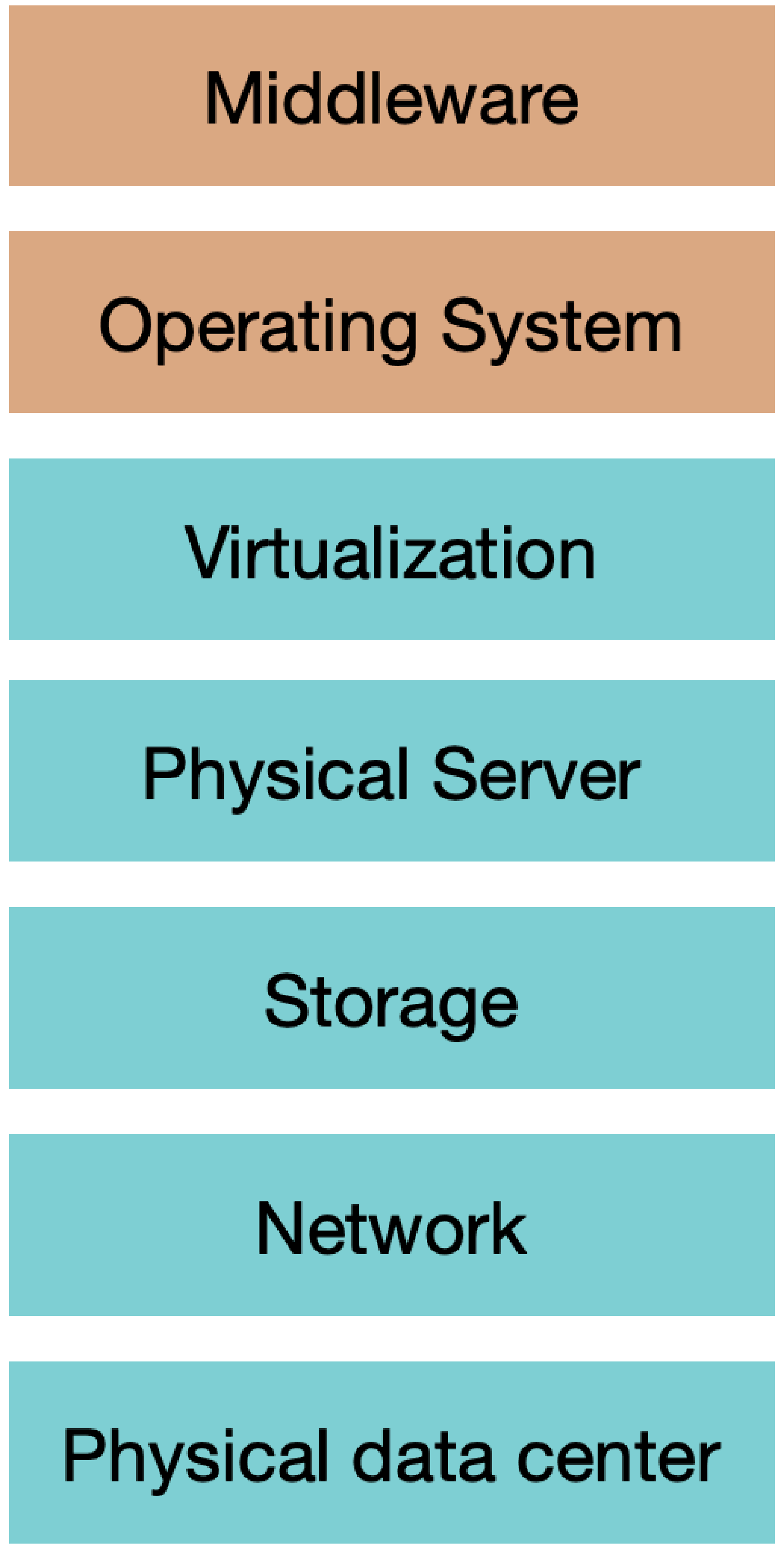


Cloud infrastructure scales elastically

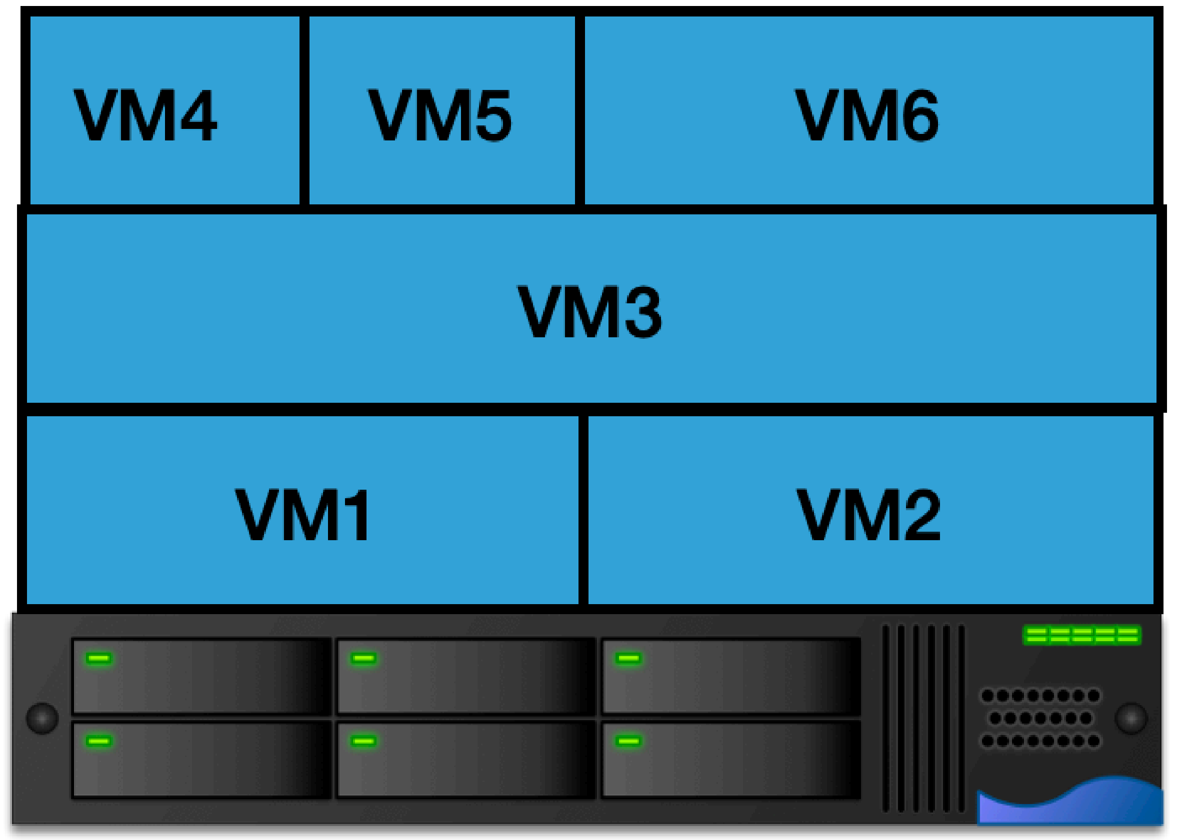
- “Traditional” computing infrastructure requires capital investment
  - “Scaling up” means buying more hardware, or maintaining excess capacity for when scale is needed
  - “Scaling down” means selling hardware, or powering it off
- Cloud computing scales elastically:
  - “Scaling up” means allocating more shared resources
  - “Scaling down” means releasing resources into a pool
  - Billed on consumption (usually per-second, per-minute or per-hour)

Infrastructure as a Service: Virtual Machines

- Virtualize a single large server into many smaller machines
- Each VM runs its own OS
- OS limits resource usage and guarantees per-VM quality
- Administration responsibilities separated for physical machine vs virtual machines
- Examples:
- Cloud: Amazon EC2, Google Compute Engine, Azure
- On-Premises: VMWare, Proxmox



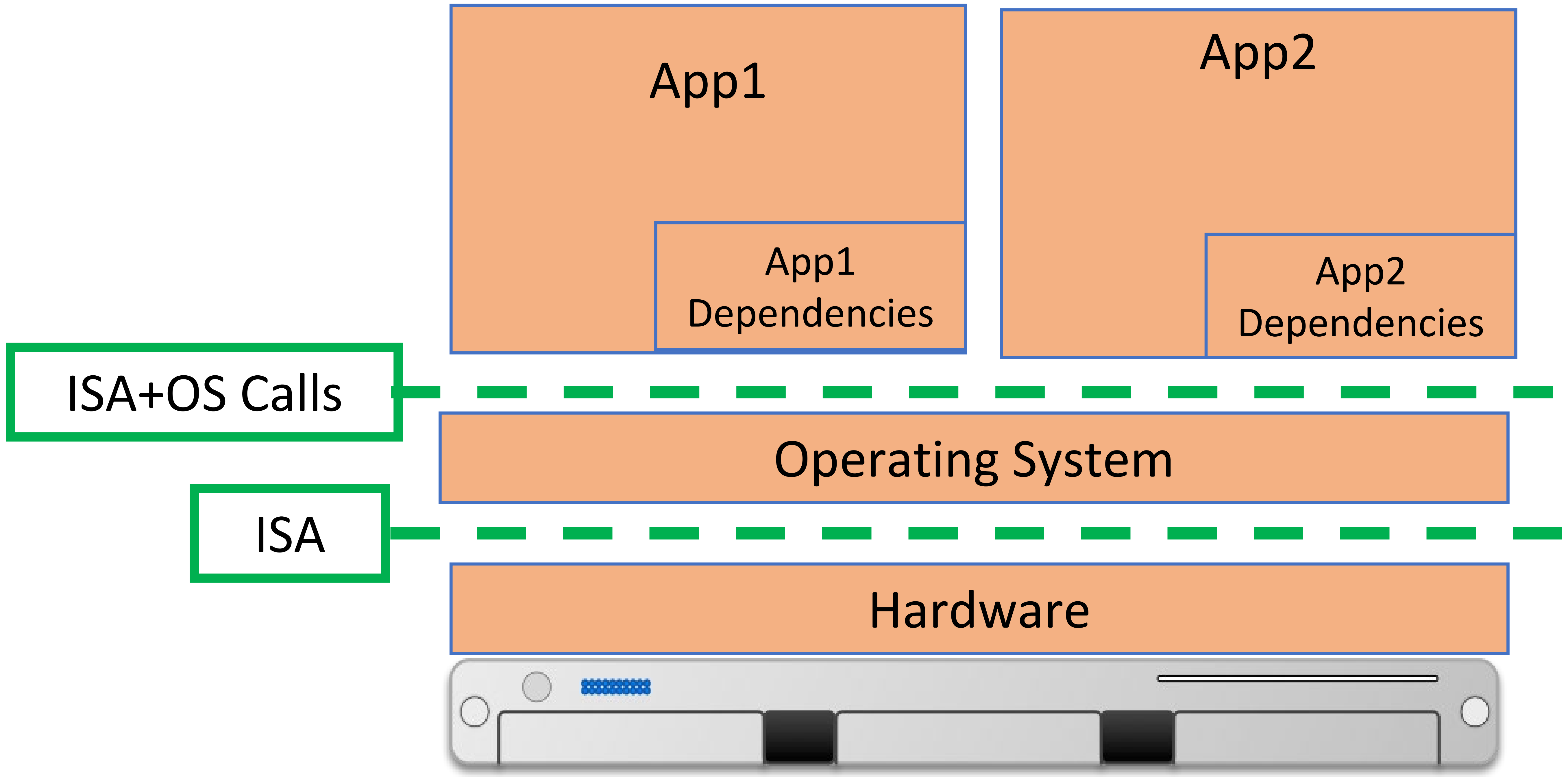
IaaS



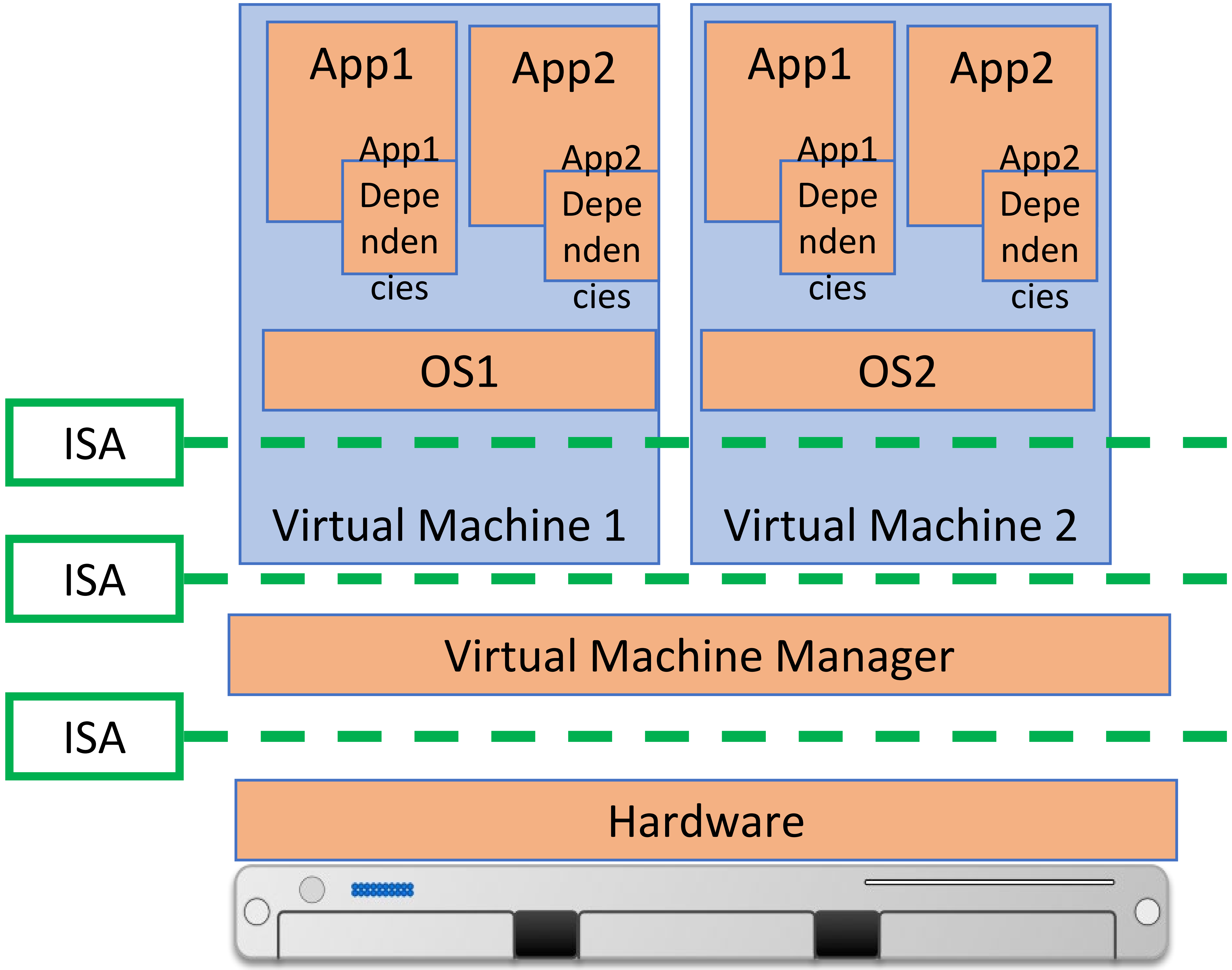
Abstracted physical machine

The operating system allows several apps to share the underlying hardware

- The “instruction set” is an abstraction of the underlying hardware
- The operating system presents the same abstraction + OS calls.



A virtual machine layer allows several different operating systems to share the same hardware



Virtual Machines facilitate multi-tenancy

- Multi-Tenancy
  - Multiple customers sharing same physical machine, oblivious to each other
- Decouples application from hardware
  - virtualization service can provide “live migration” transparent to the operating system, maximizing utilization
- Faster to provision and release
  - VM v. physical machines == ~mins v. ~hours (days?)

Virtual Machines to Containers

- Each VM contains a full operating system
- What if each application could run in the same (overall) operating system? Why have multiple copies?
- Advantages to smaller apps:
  - Faster to copy (and hence provision)
  - Consume less storage (base OS images are usually 3-10GB)

Containers run layered images, reducing storage space

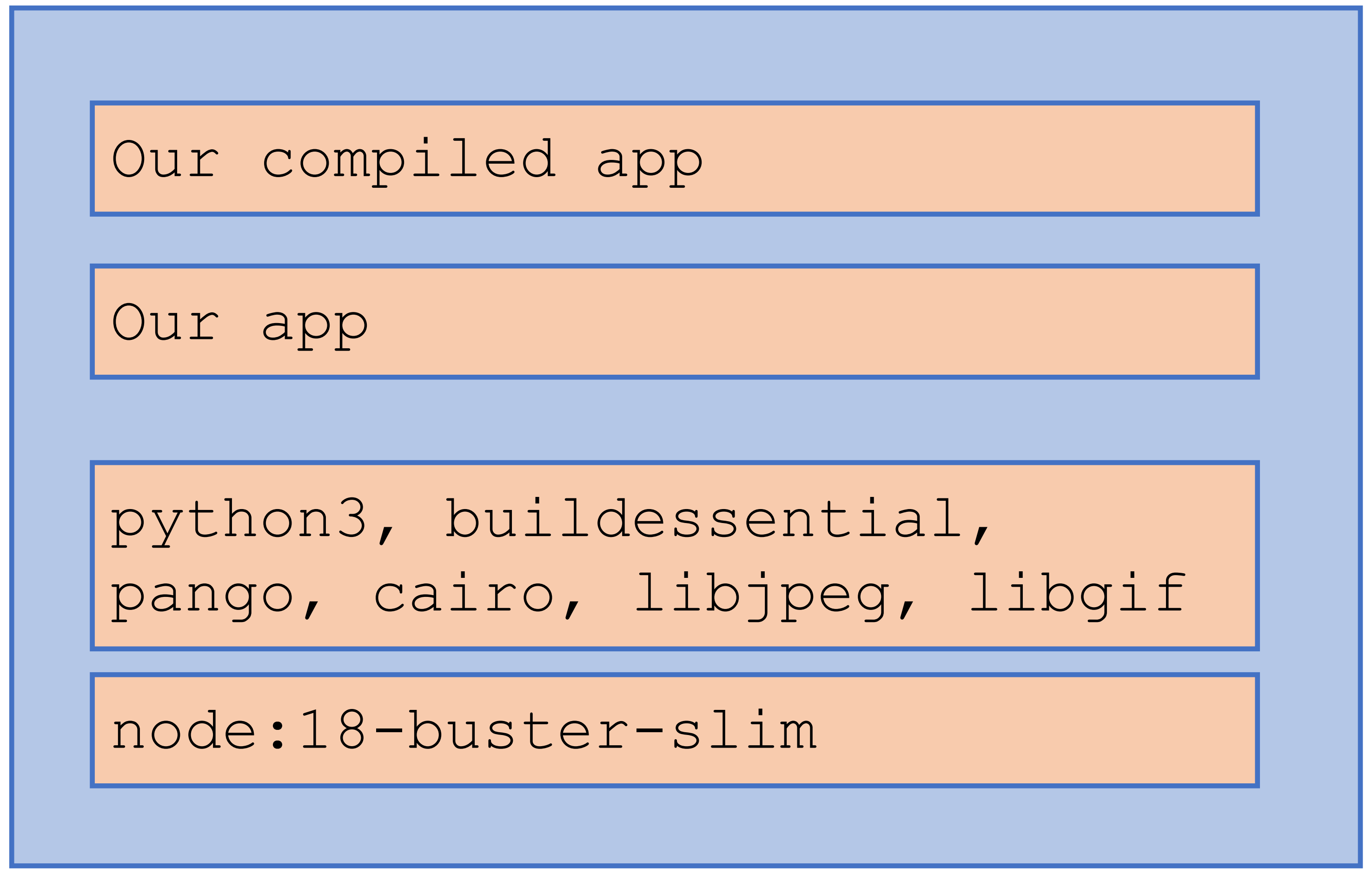
- Images are defined programmatically as a series of “build steps” (e.g. Dockerfile)
- Each step in the build becomes a “layer”
- Built layers can be shared and cached
- To run a container, the layers are linked together with an “overlay” filesystem

```
FROM node:18-buster-slim
RUN apt-get update && apt-get install python3
build-essential libpango1.0-dev libcairo2-dev
libjpeg-dev libgif-dev -y

RUN mkdir -p /usr/src/app
WORKDIR /usr/src/app
COPY ./ /usr/src/app

RUN npm ci
RUN npm run build
CMD [ "npm", "start" ]
```

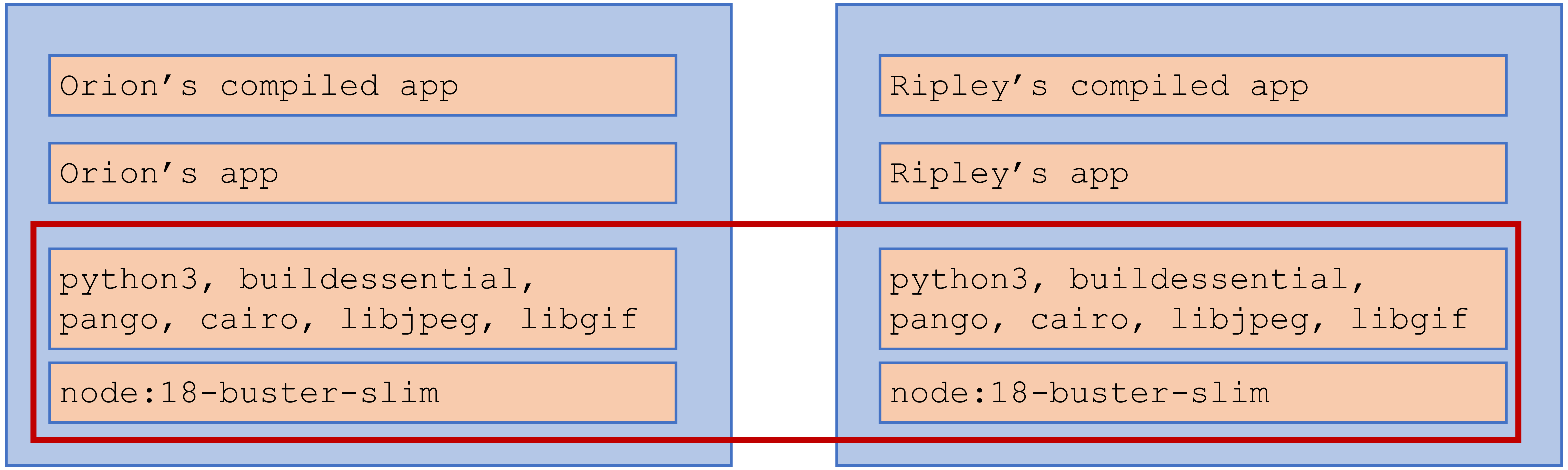
Example image specification (Dockerfile)



Example image, with layers shown

Containers run layered images, reducing storage space

- Many images may share the *same* lower layers (e.g. OS, NodeJS, some system dependencies)
- Layers are shared between images
- Multi-tenancy: *N* running containers only require *one* copy of each layer (they are read-only)



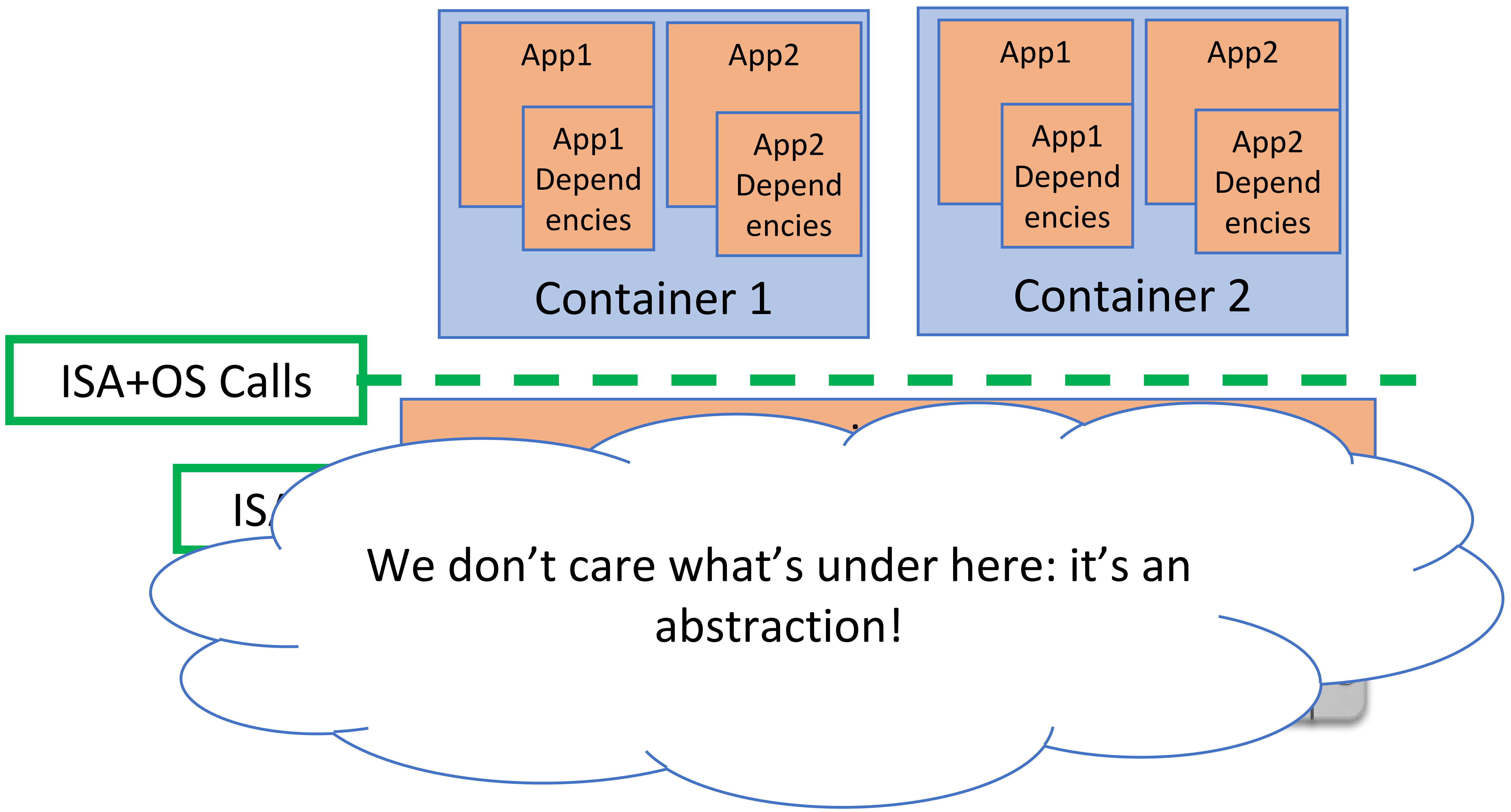
Two images, sharing two layers

A container contains your apps and all their dependencies

- Each application is encapsulated in a “lightweight container,” includes:
  - System libraries (e.g. glibc)
  - External dependencies (e.g. nodejs)
- “Lightweight” in that container images are smaller than VM images - multi tenant containers run in the OS
- Cloud providers offer “containers as a service” (Amazon ECS Fargate, Azure Kubernetes, Google Kubernetes)

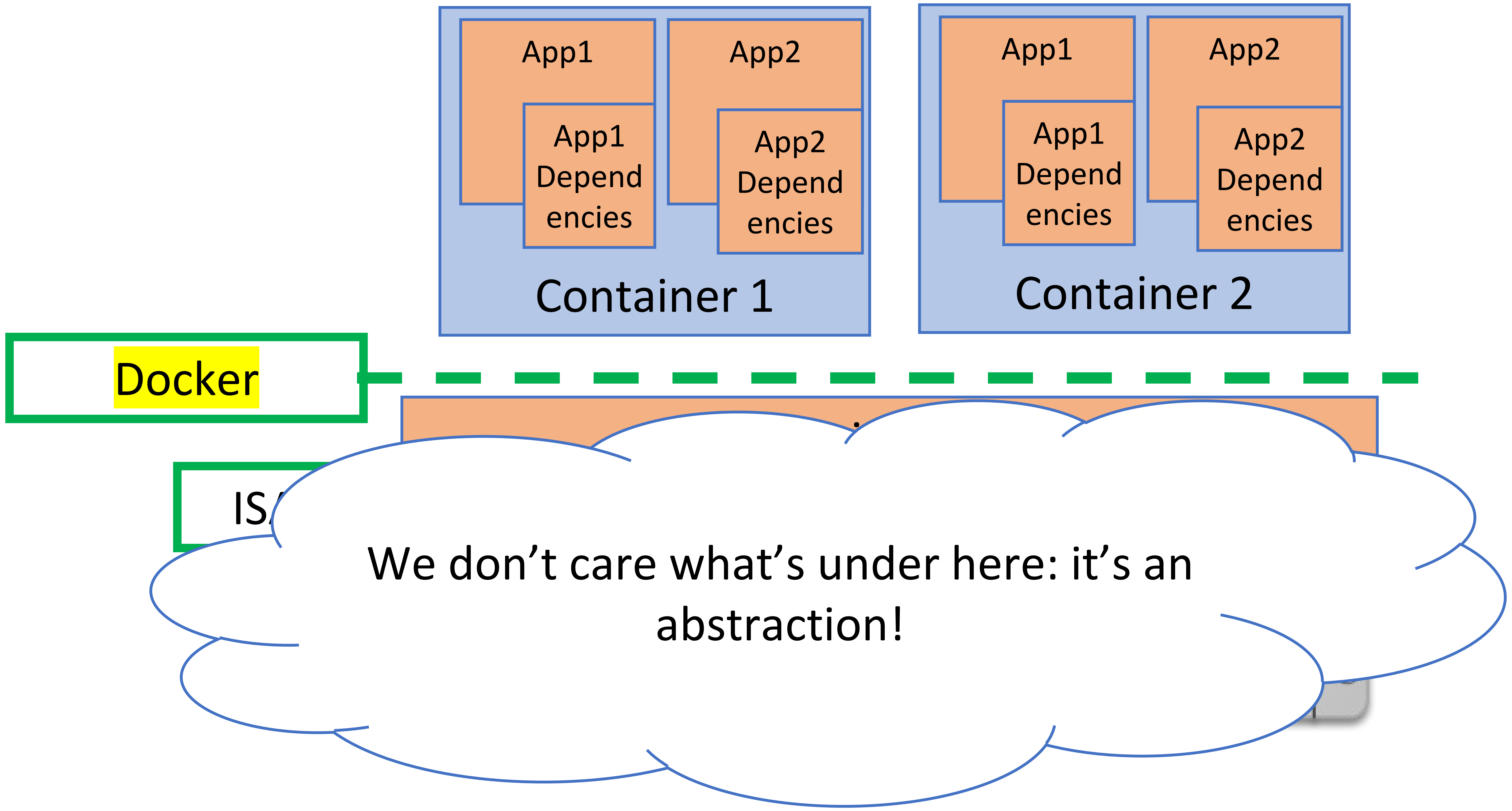
XaaS: Containers as a Service

- Vendor supplies an on-demand instance of an operating system
  - e.g.: Linux version NN
- Vendor is free to implement that instance in a way that optimizes costs across many clients.



Docker is the prevailing container platform

- Docker provides a standardized interface for your container to use
- Many vendors will host your Docker container
- An open standard for containers also exists ("OCI")

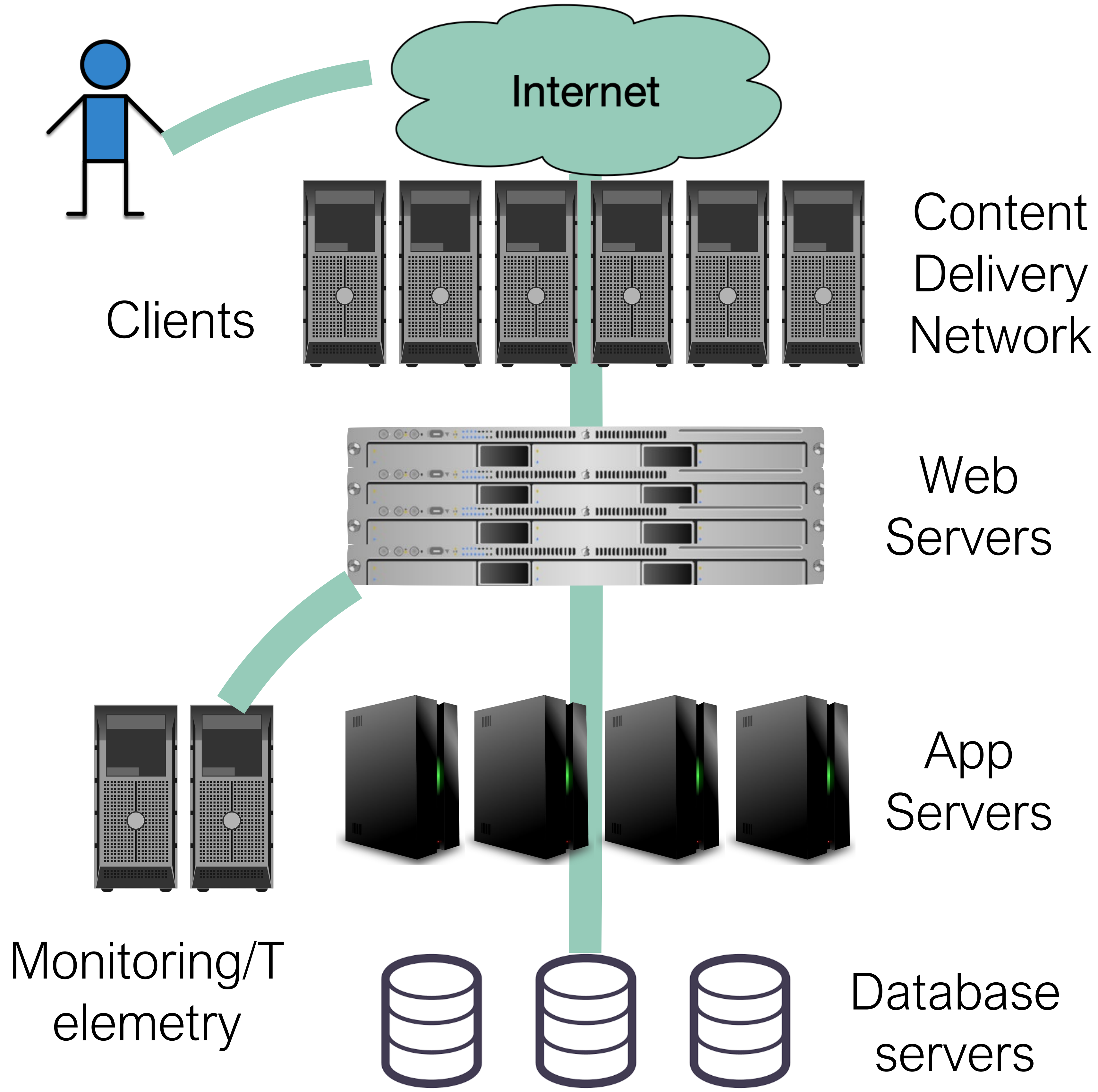


Tradeoffs between VMs and Containers

- Performance is comparable
- Each VM has a copy of the OS and libraries
  - Higher resource overhead
  - Slower to provision
  - Support for wider variety of OS’s
- Containers are “lightweight”
  - Lower resource overhead
  - Faster to provision
  - Potential for compatibility issues, especially with older software

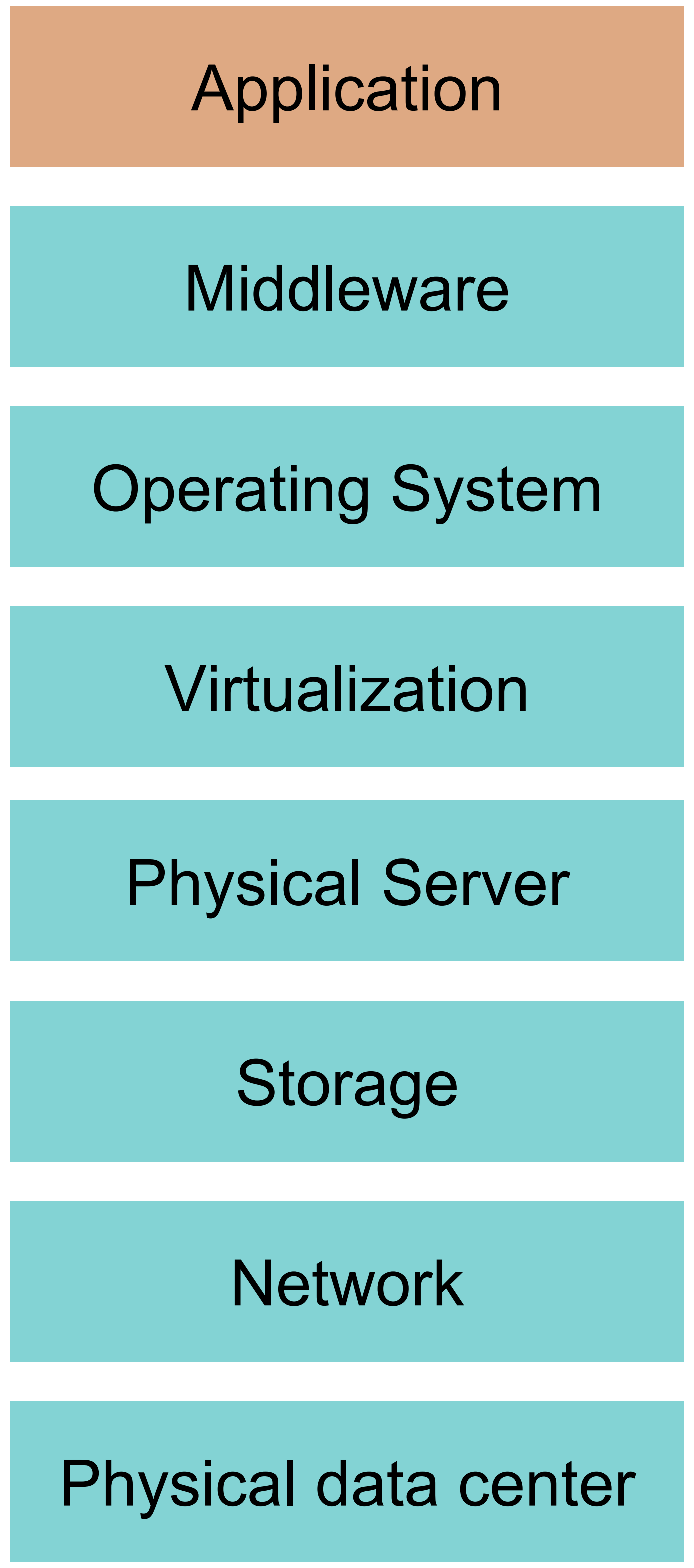
Platform-as-a-Service: vendor supplies OS + middleware

- Middleware is the stuff between our app and a user's requests:
  - Content delivery networks: Cache static content
  - Web Servers: route client requests to one of our app containers
  - Application server: run our handler functions in response to requests from load balancer
  - Monitoring/telemetry: log requests, response times and errors
- Cloud vendors provide managed middleware platforms too: "Platform as a Service"



PaaS is often the simplest choice for app deployment

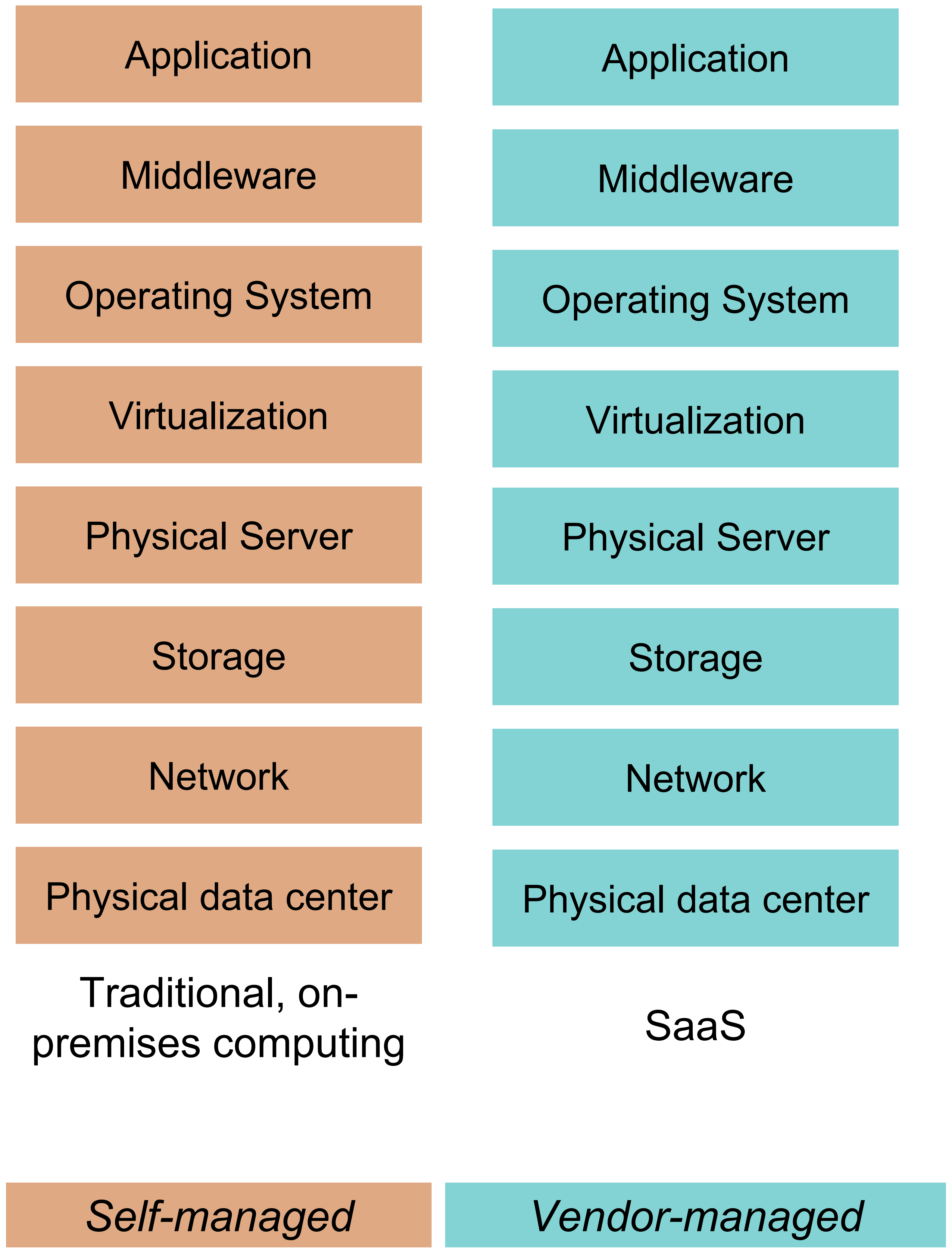
- **Platform-as-a-Service** provides components most apps need, fully managed by the vendor: load balancer, monitoring, application server
- Some PaaS run your app in a container: Heroku, AWS Elastic Beanstalk, Google App Engine, Railway, Vercel…
- Other PaaS run your apps as individual functions/event handlers: AWS Lambda, Google Cloud Functions, Azure Functions
- Other PaaSs provide databases and authentication, and run your functions/event handlers: Google Firebase, Back4App



PaaS

Self-managed vs Vendor-managed Infrastructure Tradeoffs

- Consider who manages each tier in the stack
- Benefits to vendor-managed options:
  - More ways to reduce resource consumption, improve resource utilization
  - Less management burden
  - Less capital investment, more flexibility in scaling
- Benefits to self-managed options:
  - Greater flexibility to migrate between software platforms
  - More capital investment, potentially less operating expenses



Cloud Infrastructure is best for variable workloads

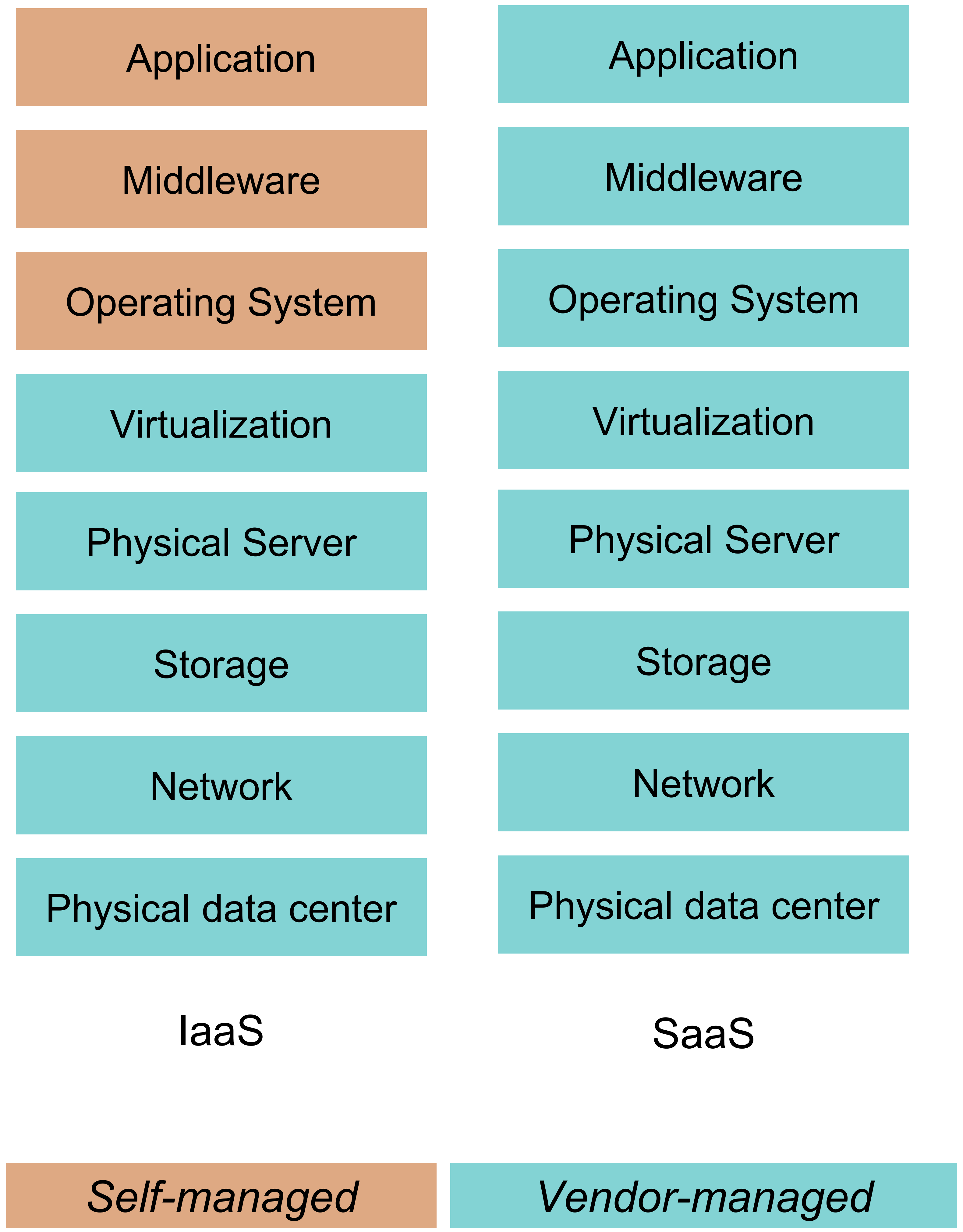
- Consider:
  - Does your workload benefit from ability to scale up or down?
  - Variable workloads have different demands over time (most common)
  - Constant workloads require sustained resources (less common)
- Example:
  - Need to run 300 VMs, each 4 vCPUs, 16GB RAM
- Private cloud:
  - Dell PowerEdge Pricing (AMD EPYC 64 core CPUs)
  - 7 servers, each 128 cores, 512GB RAM, 3 TB storage = $162,104
- Public cloud:
  - Amazon EC2 Pricing (M7a.xlarge instances, $0.153/VM-hour)
  - 10 VMs for 1 year + 290 VMs for 1 month: $45,792.90
  - 300 VMs for 1 year: $402,084.00

Public clouds are not the only option

- “Public” clouds are connected to the internet and available for anyone to use
  - Examples: Amazon, Azure, Google Cloud, DigitalOcean
- “Private” clouds use cloud technologies with on-premises, self-managed hardware
  - Cost-effective when a large scale of baseline resources are needed
  - Example management software: OpenStack, VMWare, Proxmox, Kubernetes
- “Hybrid” clouds integrate private and public (or multiple public) clouds
  - Effective approach to “burst” capacity from private cloud to public cloud

Software as a Service adds more vendor-managed apps

- Providers may also develop custom software offered only as a service
- Examples:
  - PostgreSQL (open source)
  - Twilio Programmable Video (proprietary chat)



“X as a Service" offers several abstractions to choose from depending on your needs

- Vendor manages different levels of the stack, achieving economies of scale
- When would you choose one over the other?
- Explore some options at https://comparecloud.in/

Application	Application	Application	Application
Middleware	Middleware	Middleware	Middleware
Operating System	Operating System	Operating System	Operating System
Virtualization	Virtualization	Virtualization	Virtualization
Physical Server	Physical Server	Physical Server	Physical Server
Storage	Storage	Storage	Storage
Network	Network	Network	Network
Physical data center	Physical data center	Physical data center	Physical data center
Traditional, on-premises computing	IaaS	PaaS	SaaS

Self-managed

Vendor-managed

Review

- You should now be able to…
  - Explain what “cloud” computing is and why it is important
  - Explain why shared infrastructure is important in cloud computing
  - Describe the difference between virtual machines and containers
  - Discuss trade-offs that you might consider for self or vendor-managed platforms