Recall: where we are

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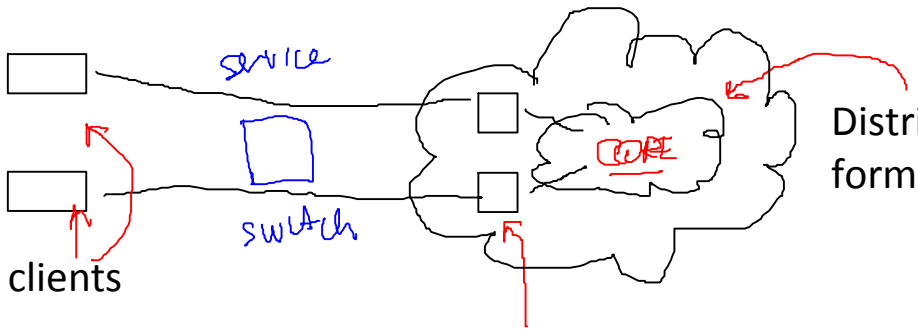
Recall: where we are

Can "scale" cloud applications "on the edge" by **adding server instances.**

(So far, haven't considered scaling the **interior** of the cloud).



Distributed services form an **inner core** (JDO)

App servers form an **outer edge**

Point for today

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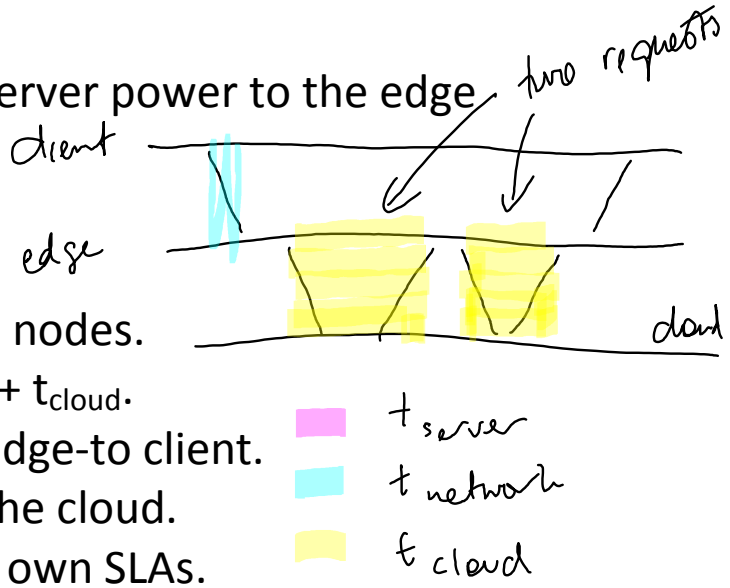
The safe operating bounds of the edge nodes of the cloud are based upon:

- how demand changes over time
- how quickly you can re-allocate server power to the edge nodes.
- key tool: virtualization.



Assumptions for today's discussion

- Flowless switching between edge nodes.
- Response time $P = t_{server} + t_{network} + t_{cloud}$.
- $t_{network}$ is just client-to-edge and edge-to client.
- t_{cloud} includes networking inside the cloud.
- Both of these are subject to their own SLAs.
- So we concentrate on keeping t_{server} within reasonable bounds.

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Virtualization

So far: we know how to throw server power at an application to react to demand and **increase throughput**.

Next step: how to switch a server from one role to another.

Key tool: **server virtualization**

What is virtualization?

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What is virtualization?

In its simplest form, creating a fictional version of a thing that acts like the real thing.

This is called "virtualizing a thing".

Many possible things...

A very broad term

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Several kinds of virtualization:

Machine virtualization: thinking of a **physical machine** as "hosting" one or more **virtual machines**.

I/O virtualization: sharing an I/O device with several running operating systems, perhaps even on different physical machines.

Filesystem virtualization: making one instance of an operating system behave as if it were multiple, distinct instances by controlling filesystem access.

Program virtualization: program is compiled to run on a virtual machine, e.g., the Java Virtual Machine (JVM).

Machine virtualization

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Mostly, we'll be concerned with machine (hardware) virtualization:

make **one physical machine** act like **many virtual machines.**

"host" various OS instances (either similar or different) on different virtual machines.

Turn OS instances on or off as needed.

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Why we need machine virtualization

- Repurposing a server can require **rebuilding** the whole operating system. This can take (relatively) a lot of time.
- Virtualizing the machine allows two or more operating systems to share it. (One can be running normally even while another is being built.)
- Also, whole operating system instances can be prebuilt and latent, ready to start running when needed.

Machine and I/O virtualization

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Most things about machine virtualization are easy.

- Running two operating systems is like running two "programs".
  - Separate sections of memory.
  - Separate disk.

Hard part: sharing resources and devices.

- Devices have **state**.
  - A disk drive doesn't take well to being asked to read something **during** a write.
  - An **I/O** driver is a piece of software designed to maintain proper device state.

Therefore, most of the work of **machine virtualization** is **I/O virtualization.**

Some common attributes

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Some common attributes of all I/O virtualization strategies.

- Each device has **one real driver.**
- Other drivers may seem to contact the device directly, but in fact, they talk through that one "master" driver.
- Main difference between strategies: **where that master driver is located.**

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The hypervisor

- Best thought of as a **miniature operating system** for the machine
- Runs instances of operating systems as if they were **application programs**!
- Each instance
  - is (theoretically!) **unaware** of the other instances.
  - has its **own memory and disk.**
  - Is **scheduled** to use the CPU(s) by the **hypervisor.**

Two virtualization approaches

- VMWare: closed-source hypervisor
  - http://www.vmware.com
- Xen: open-source hypervisor
  - http://www.xen.org/files/Marketing/HowDoesXenWork.pdf

VMWare virtualization

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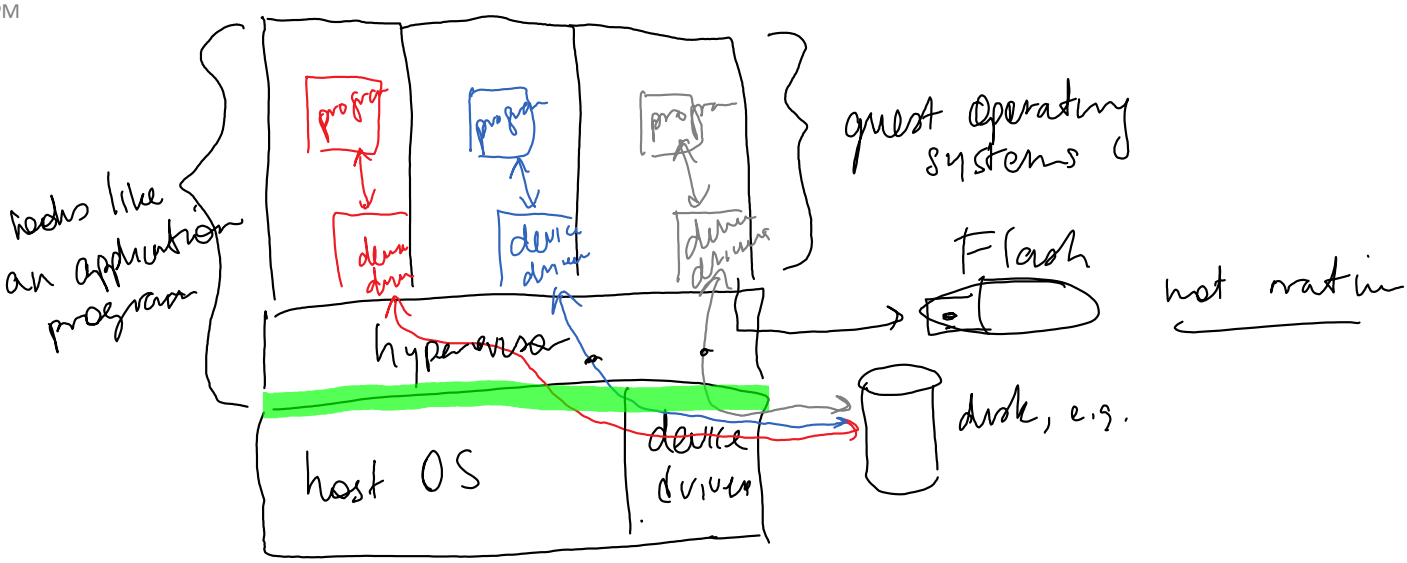

XEN virtualization

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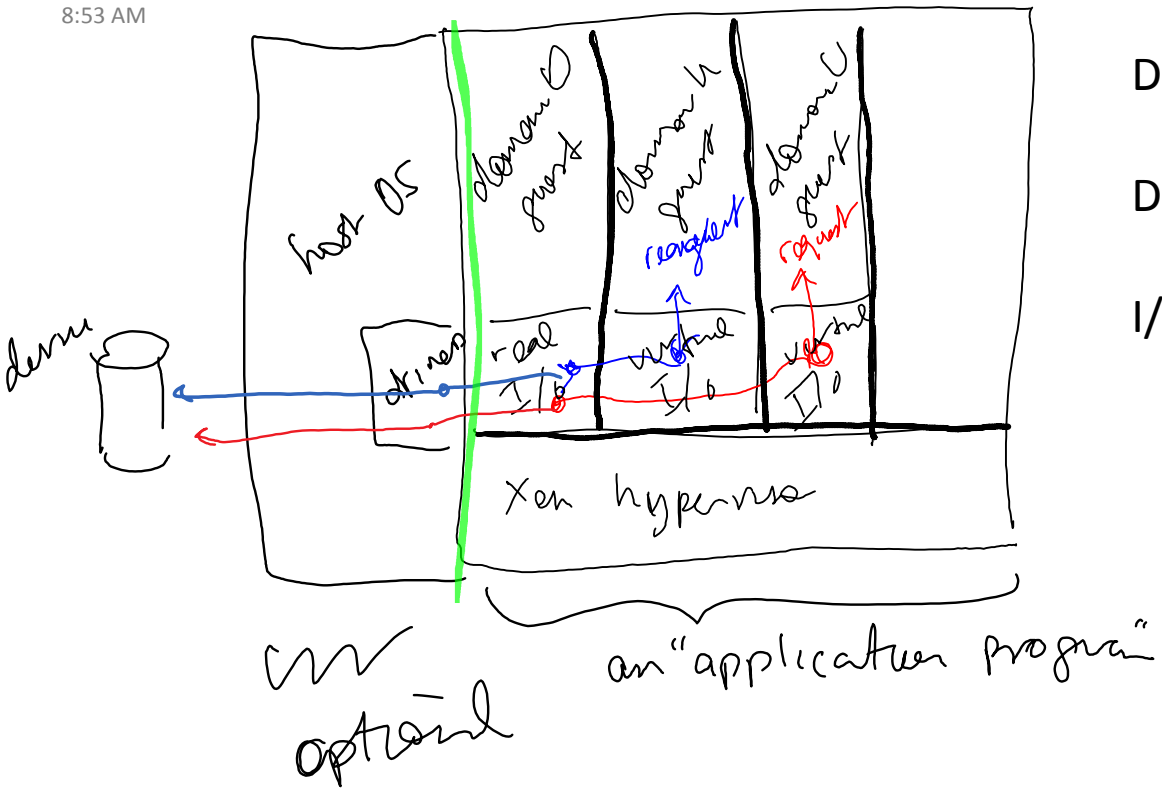

Domain 0 guest:
Does I/O
Domain U guest:
Regular OS
I/O done **outside hypervisor.**

Machine Virtualization requires I/O virtualization

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Two keys to machine virtualization

Meta-scheduling: giving each virtual machine a time slice of the real machine.

I/O virtualization: making sure that each machine gets a consistent view of each I/O device.

Meta-scheduling

- Give each OS a chance to run in turn.
- Round-robin, no priority.
- "Slows down" each OS by the same amount.
- Can give more "busy" guest OS's more time.

But...

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But…

In this course we are not really concerned about how virtualization works

Rather, we are concerned with how to use it to obtain cloud-like behavior.

Arguments for machine virtualization

Latency hiding: OS and application instances spend much of their time "waiting" for data.

Server consolidation: easier to manage one physical server instead of multiple ones.

Conflict avoidance: application instances can require conflicting versions of OS instances.

Online build: can build OS instances while others are running.

Quick deployment: can hold OS instances "in reserve" and deploy them very quickly.

Quick "sleep" and "wake": can boot an instance and then turn it off (sleep) until needed.

Two requests don't take 2x CPU time

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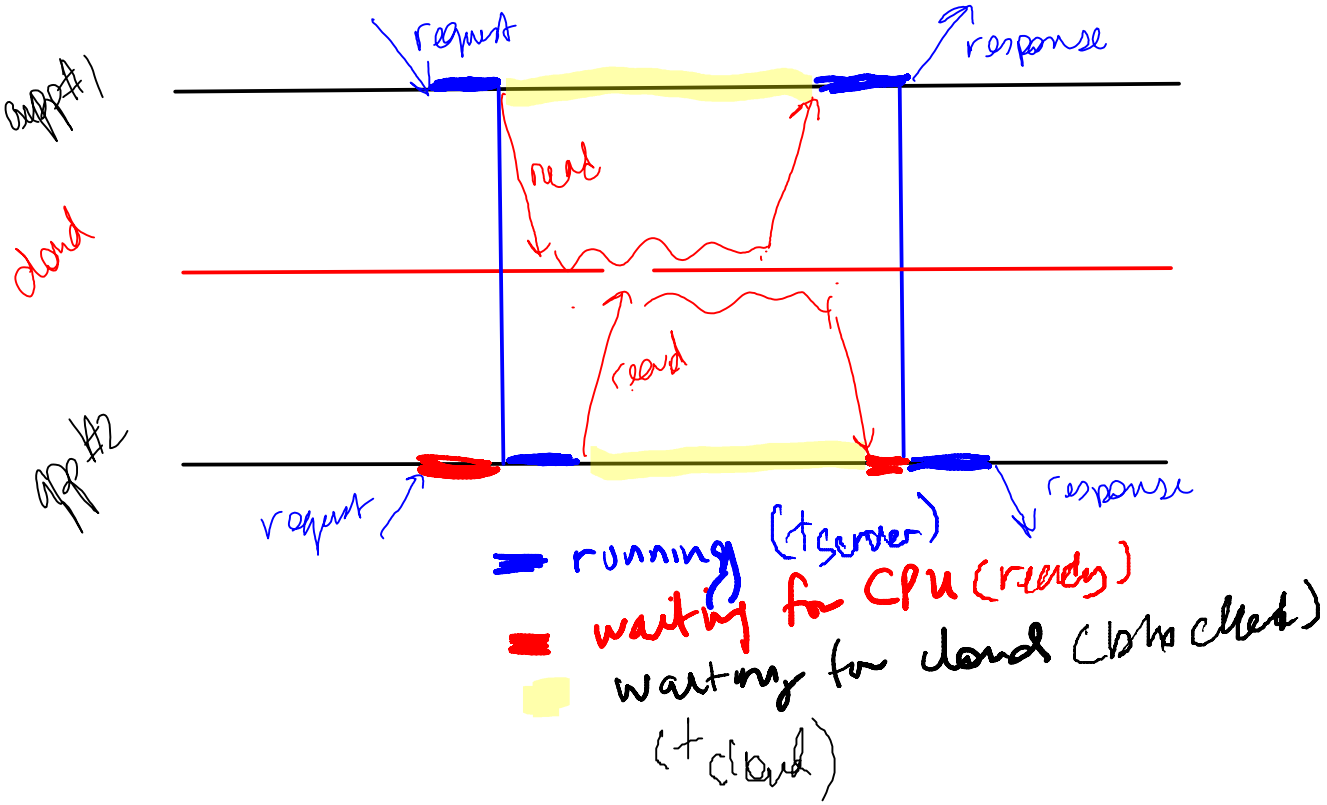

Latency hiding

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Cloud apps spend much of their time "waiting for the cloud" to return data.

Example: read **blocks** and **waits** until target data is known to be consistent.

So, multiple cloud apps can run on the **same hardware** and use the time that other apps **spend waiting**.

This is called **latency hiding.**

Deployment time

- It takes time from deciding to deploy a new server instance to time when it is available for switching.
- On physical hardware:
  - **can take 30 minutes** to build a server instance.
- On virtual machine
  - **Can build a server instance in advance** and keep it available and unused.
  - **Can share memory** between (exclusively activated) instances.
  - **Disk can't be shared (easily).**
- In either case,
  - **60 seconds** to boot a server instance.
  - **10 seconds** to wake up a sleeping instance.

Why is deployment time important?

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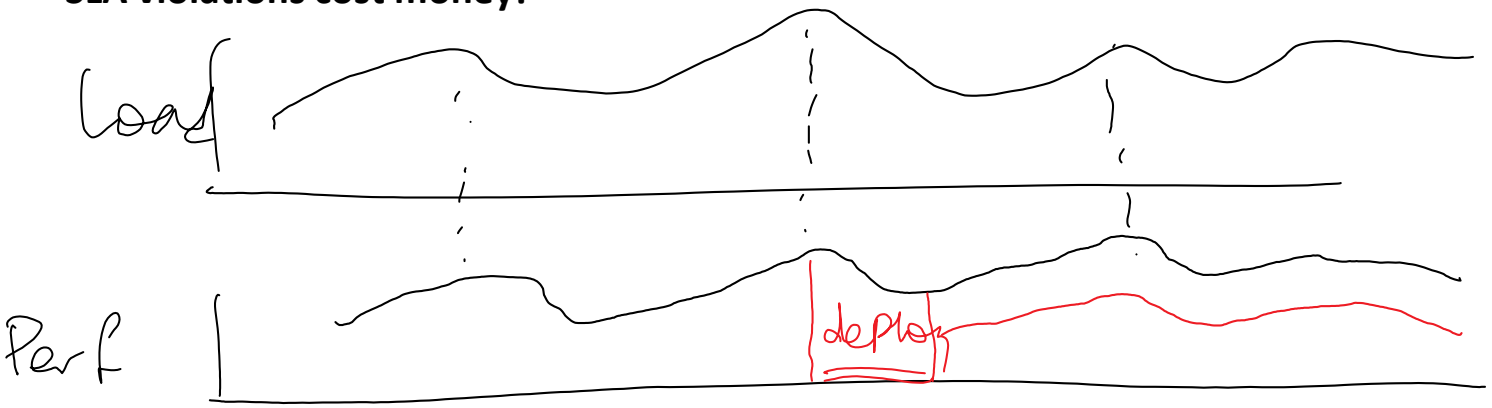
Why is deployment time important?

- Demand **changes** over time.
- SLA limits are **constant** over time.
- Response time **increases with demand.**
- Speed with which one can deploy a server determines **safety margin** for **avoiding SLA violations.**
- **SLA violations cost money!**



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Scalability and Elasticity

Scalability: a property of the **application** that allows deployment to **scale with demand** to preserve response time.

An application is **scalable** if there is no limit to the number of application instances that can handle requests, so that demand is met with instances.

Elasticity: a property of the **environment** in which an application is deployed, that allows the environment to **react to demand** by re-deploying the application to preserve response time**.**

An environment is **elastic** if infrastructure is present to allow dynamic demand-based increase or decrease in active application instances.

Elasticity and SLAs

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The "reason" for elasticity is SLAs

- When one is nearing an SLA violation, "deploy more server instances" to cope with demand.
- When demand is low, "decommission some server instances" to save operational costs.

Why virtualization is important to elasticity

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Why virtualization is important to elasticity

- Avoiding SLA violations requires rapid deployment
- Safe zone for performance depends upon relationship between **maximum load growth rate** and **speed of deployment.**

Some notation

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Some notation:

P = performance = time spent between request and response.

$P_{minimum}$ = minimum theoretical response time.

P_{SLA} = SLA upper bound on response time.

We want $P_{minimum} \leq P \leq P_{SLA}$

But remembering our notation from last time:

t_{server} = time spent in server to be scaled.

$t_{network}$ = time spent in network communications.

t_{cloud} = time spent waiting for cloud.

$t_{minimum}$ = theoretical minimum server time.

t_{SLA} = maximum time that can be spent on server to comply with SLA.

We want $P_{minimum} = t_{minimum}+t_{network}+t_{cloud}$

$\leq P = t_{server} + t_{network} + t_{cloud}$

$\leq P_{SLA} = t_{SLA} + t_{network} + t_{cloud}$

$P_{minimum} \leq P \leq P_{SLA}$ whenever $t_{minimum} \leq t_{server} \leq t_{SLA}$.

(Here, and from now on, t_{cloud} includes cloud communication time and $t_{network}$ is just from client to edge and back.)

For simplicity

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For simplicity,

Assume t_{cloud}, $t_{network}$ are (relatively) constant.

Then what varies is t_{server}.

Assume we're talking (for today) about "average" behavior.

The naïve approach

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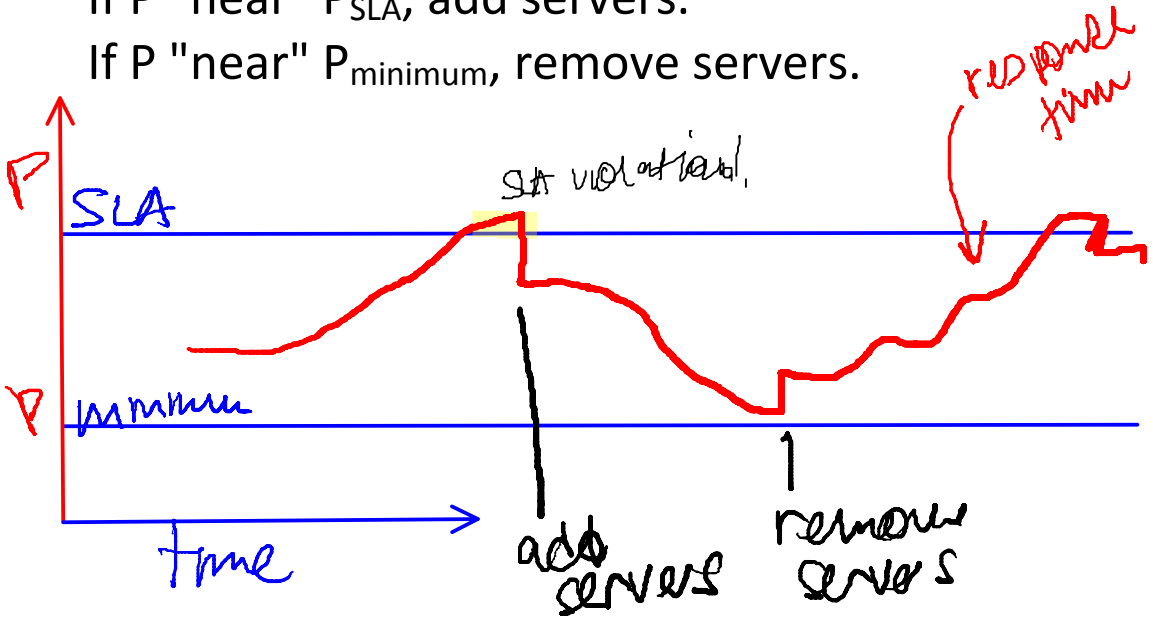
The naïve approach:

If P "near" P_{SLA}, add servers.

If P "near" $P_{minimum}$, remove servers.



Problems with the naïve approach

- When you add servers, you are **already in violation!**
- **How close is "close enough"** to $P_{minimum}$ to remove servers?

A typical strategy for SLA compliance

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Four watermarks

- $t_{\mathbf{minimum}}$: theoretical minimum server time, leads to
- $P_{minimum}$: minimum response time.
- $t_{sufficient}$: sufficient server response time, leads to
- $P_{sufficient}$: sufficient overall response time.
- t_{safe}: worst acceptable server response time, leads to
- P_{safe}: worst acceptable overall response time.
- t_{SLA}: SLA violation boundary, leads to
- P_{SLA}: worst penalty-free overall response time.

Typical strategy for avoiding SLA violation:

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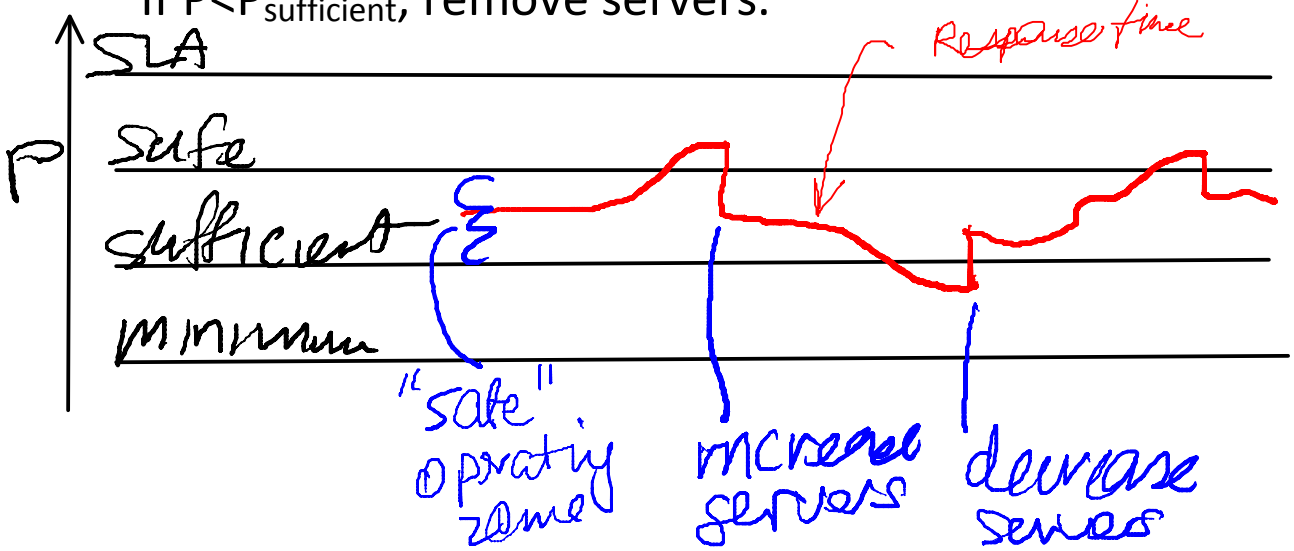
Typical strategy for avoiding SLA violations:

If $P>P_{safe}$, add servers.

If $P<P_{sufficient}$, remove servers.



Resource thresholding

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A simple calculation:

Let P(t) be the **performance** of the application over time, e.g., average response time. We want small P(t).

Let R(t) be the **resources** allocated to the application, e.g., application instances deployed.

Let L(t) be the **load** (demand) in requests per second.

Naïve physics of P

- P(T) is a function of R(T) and L(T)!
  - As L(T) increases, P(T) increases.
  - As R(T) increases, P(T) decreases.
- We want $P(T) < P_{SLA}$ = SLA limit.
- So we need to **increase R as L increases** or -- equivalently -- **increase R as P increases.**

A simple calculation

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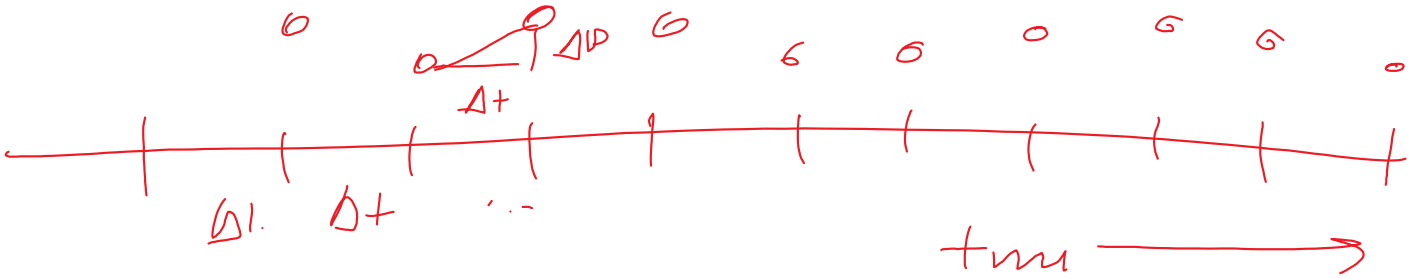
Suppose we're sampling performance at some fixed interval **Δt**.
Suppose we know the maximum rate at which P can increase; call that **M = max(ΔP/Δt)**.
Suppose that it takes us time t_{deploy} to deploy a new instance.
Let **N=** $\lceil \mathbf{t_{deploy}/\Delta t} \rceil$ where $\lceil A \rceil$ is the least integer greater than A.
This is the number of update cycles it takes to deploy an instance. N can vary between 1 (pre-deployed virtual instance) and several hundred (need to install an instance).
Then it had better be that $P+NM < P_{SLA}$.
Otherwise, the new instance has been deployed too late to help!



SLA violation avoidance

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SLA violation avoidance:

Estimate M = max ($\Delta P/\Delta t$) = the amount that P can grow by in one cycle.

Estimate N = $\lceil t_{deploy}/\Delta t \rceil$ = number of measurement cycles needed to deploy an instance.

If $P+NM > P_{SLA}$, we are risking a violation; add application instances to cope.

Thus $P < P_{SLA} - NM \equiv \mathbf{P_{safe}}$

Defining $P_{safe} \equiv t_{safe}+t_{network}+t_{cloud}$,

we get $t_{safe} = t_{SLA} - NM$

$= t_{SLA} - \lceil t_{deploy}/\Delta t \rceil \max (\Delta P/\Delta t)$.

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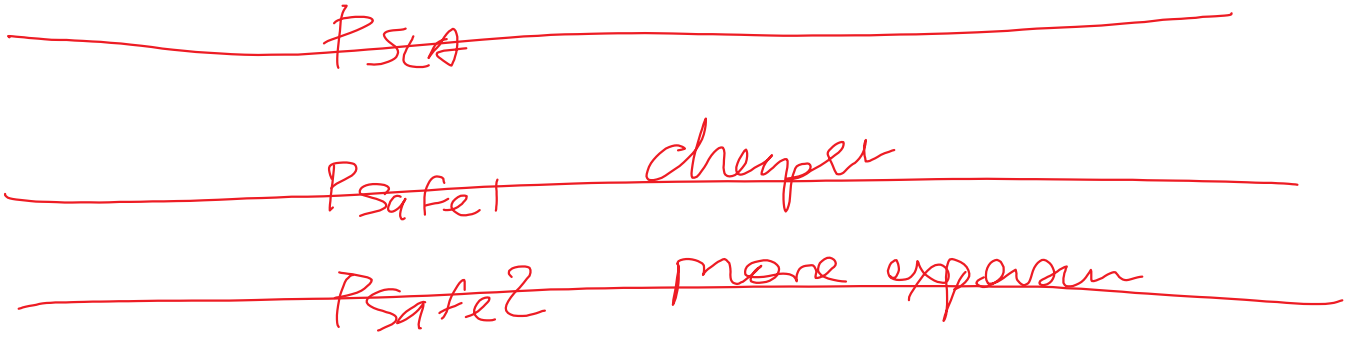
The point of this nonsense

The margin of safety t_{safe} is a function of deployment time t_{deploy} and the projected maximum load increase rate M.

In other words, **deployment time matters!**



Violation time is too late

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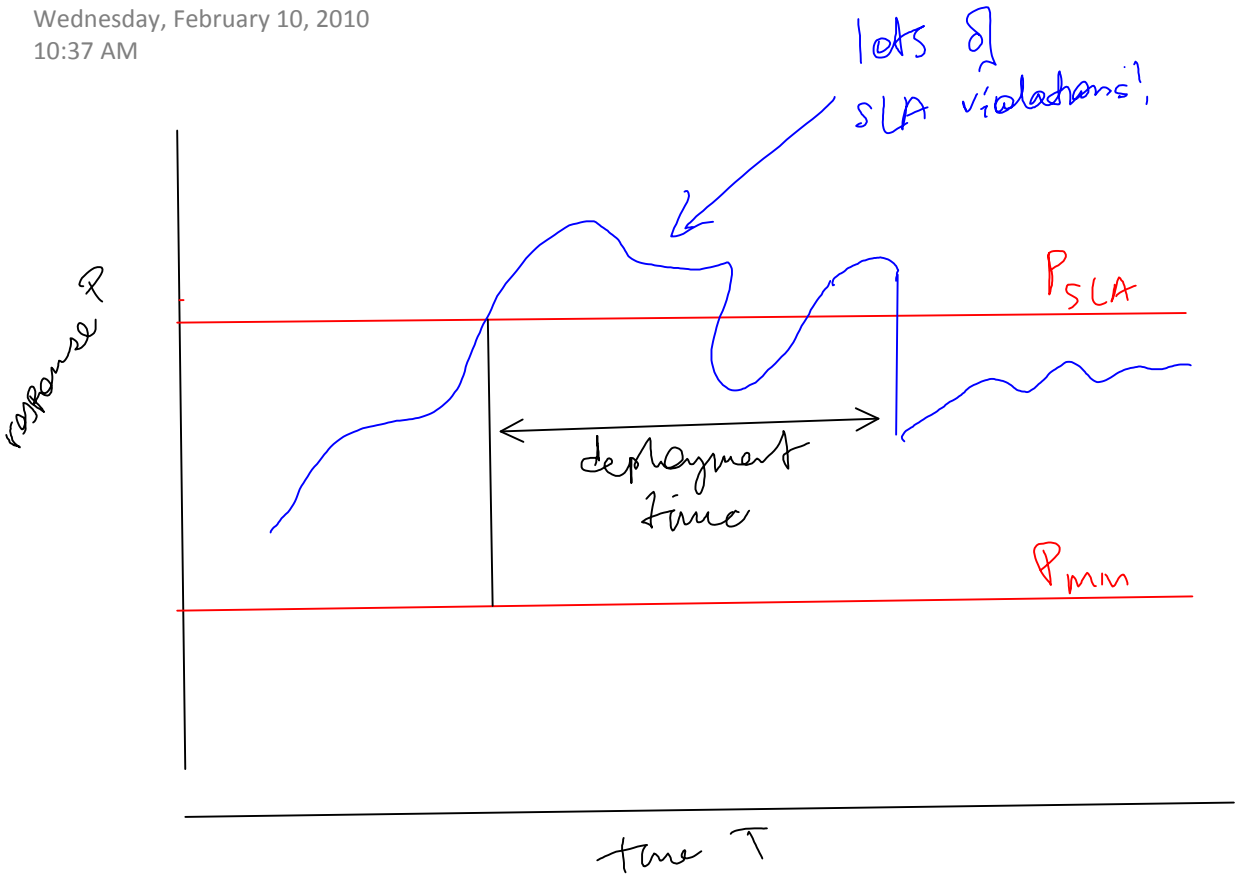

Ideal behavior

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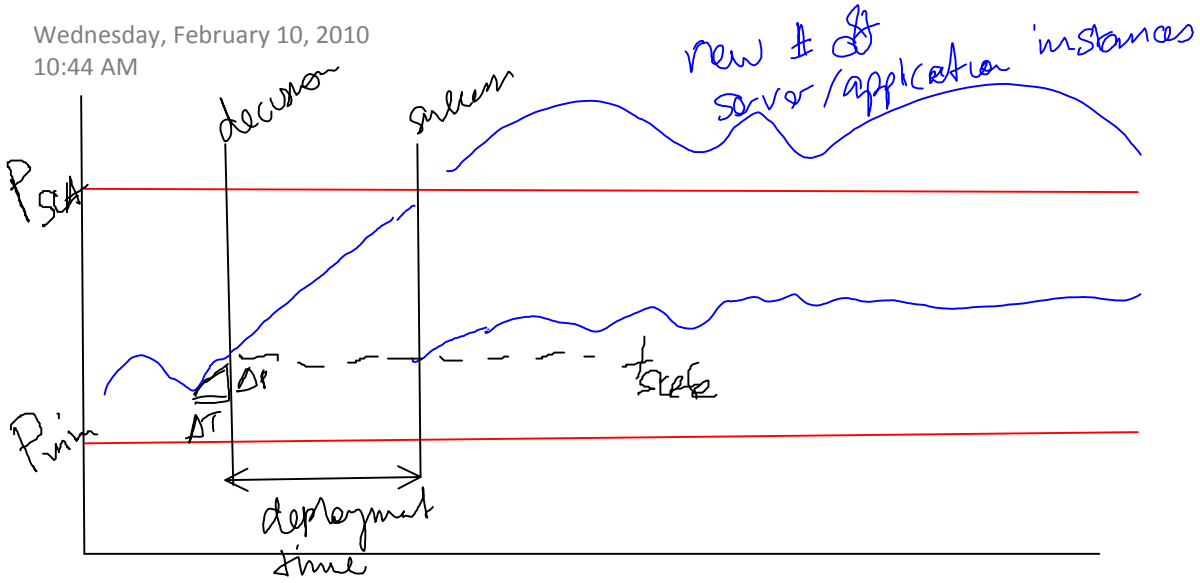

Broader picture of resource thresholding

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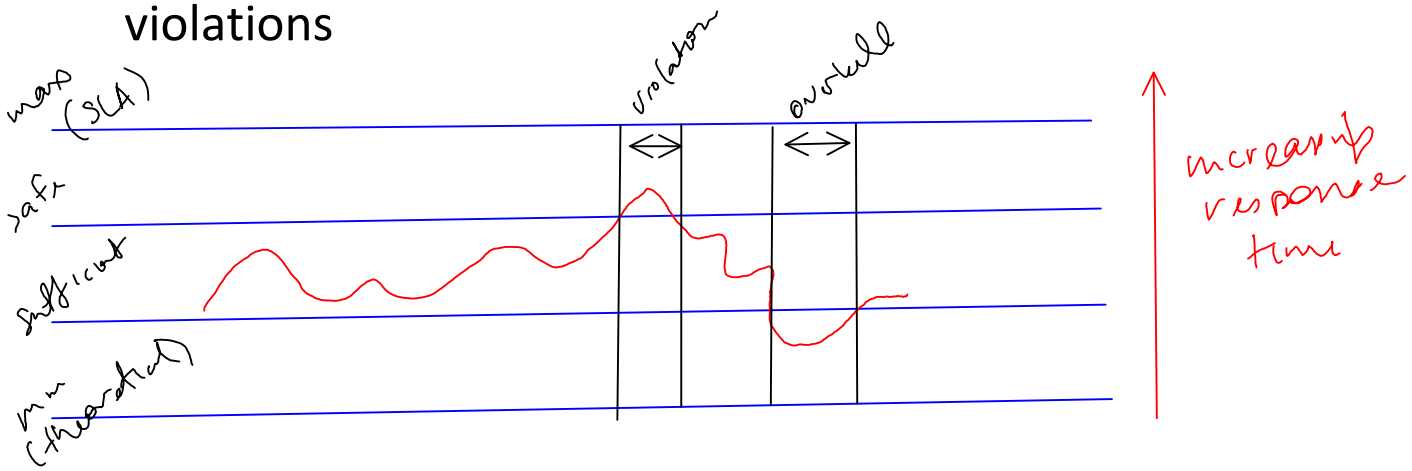
Actually two computed bounds:

- $t_{sufficient}$: how fast is fast enough.
- t_{safe}: how fast is safe in terms of avoiding SLA violations



Basic elasticity calculation

If $P > P_{safe}$, **increase instances** to bring it below P_{safe}.

If $P < P_{sufficient}$, **decrease instances** to allow it to be larger.

Why virtualization is important in clouds

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Why virtualization is important in clouds

- Quick deployment allows t_{safe} nearer to t_{SLA}.
- Which reduces the **number of deployed instances** to maintain t_{safe}.
- Which saves power, cost, etc.
- This is why virtualization is so important!

Increasing instances

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So far,

we know to keep $\mathbf{P_{sufficient} \leq P \leq P_{safe}}$ by adding or removing instances.

This gives us **time to react** to changes in demand.

But **how many instances** should we add (or remove)?

That is a longer story (next time).