Plugging Side-Channel Leaks with Timing Information Flow Control

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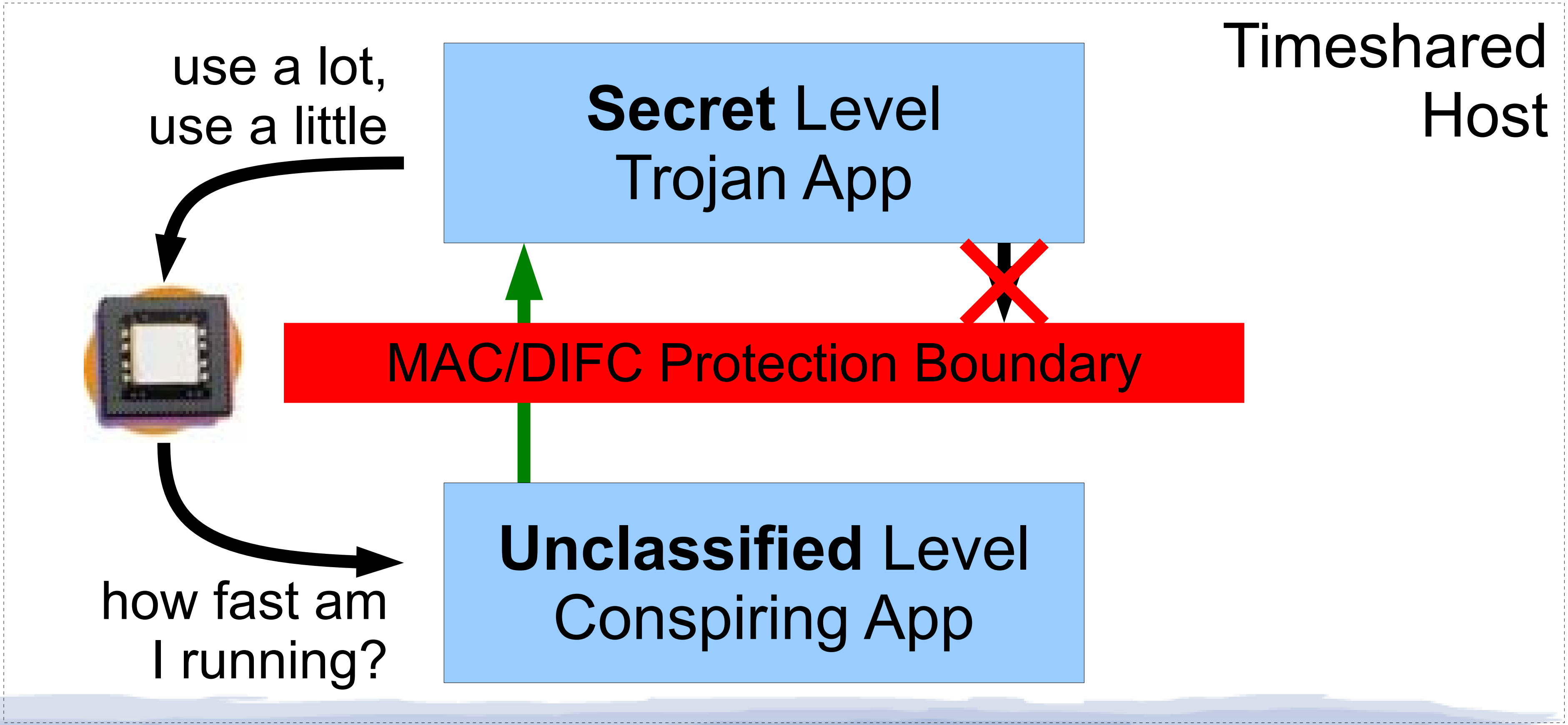
USENIX HotCloud, June 13, 2012

The Long History of Timing Attacks

- **Cooperative attacks** – apply to:
  - Mandatory Access Control (MAC) systems [Kemmerer 83, Wray 91]
  - Decentralized Information Flow Control (DIFC) [Efstathopoulos 05, Zeldovich 06]
- **Non-cooperative attacks** – apply to:
  - Processes/VMs sharing a CPU core [Percival 05, Wang 06, Acıiçmez 07, …]
  - Including VM configurations typical of clouds [Ristenpart 09]

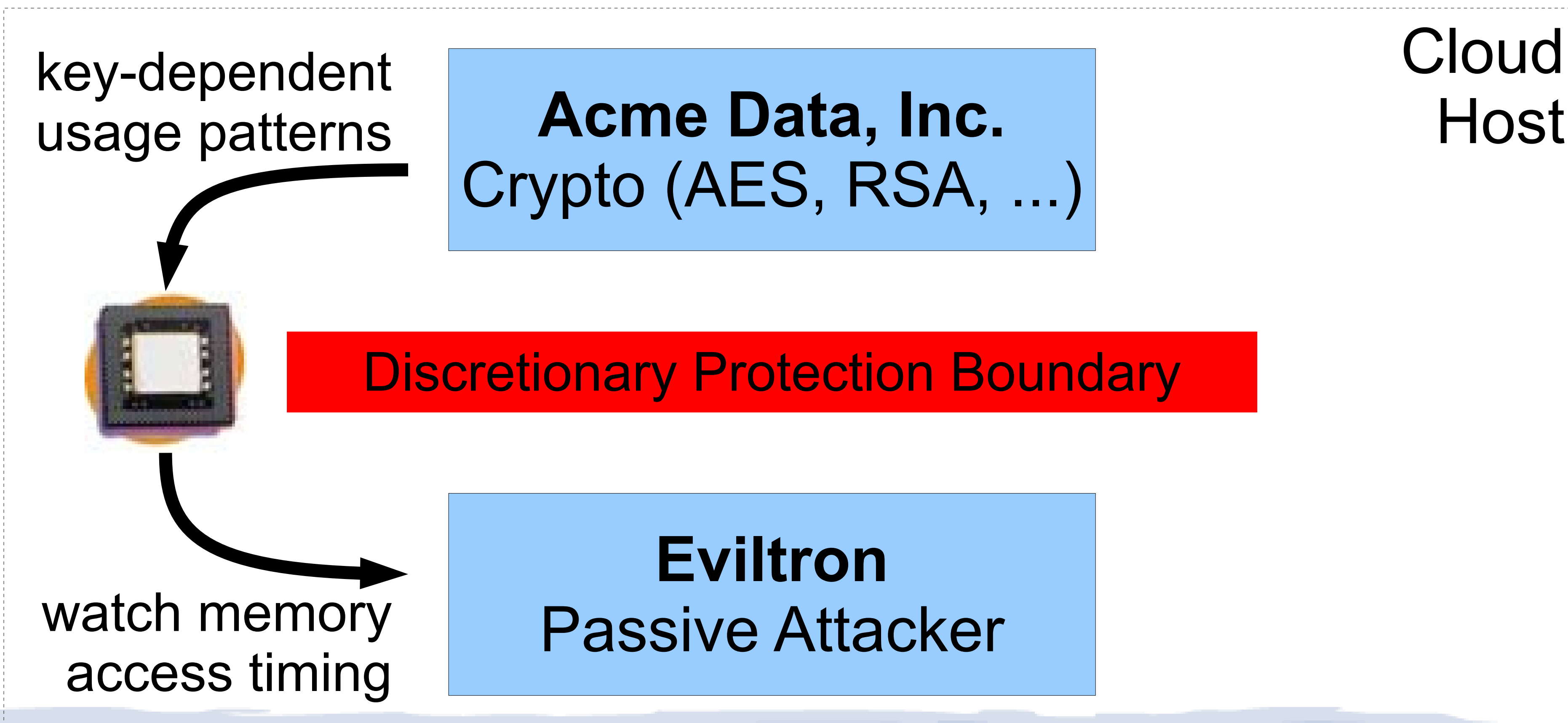
Cooperative Attacks: Example

Trojan leaks **secret** information by modulating a *timing channel* observable by **unclassified** app



Non-Cooperative Attacks: Example

Apps *unintentionally* modulate shared resources to reveal secrets when running standard code



Timing Attacks in the Cloud

The cloud *exacerbates* timing channel risks:

1. Routine co-residency
2. Massive parallelism
3. No intrusion alarms → hard to monitor/detect
4. Partitioning defenses defeat elasticity

"*Determinating Timing Channels in Compute Clouds*" [CCSW '10]

Leak-Plugging Approaches

Two broad classes of existing solutions:

- *Tweak specific algorithms, implementations*
  - Equalize AES path lengths, cache footprint, …
- *Demand-insensitive resource partitioning*
  - Requires *new or modified hardware* in general
    - Partition CPU cores, cache, interconnect, …
  - Can't oversubscribe, stat-mux resources
    - → Not economically feasible in an “elastic” cloud!

Information Flow Control

Explicitly *label* information, constrain propagation

- Old idea, recently (re-)popularized
  - DIFC, Asbestos/HiStar/Flume
  - Label variables, processes, messages, etc.
- So far, IFC avoids the timing channel issue
  - How would one “label time”?
  - What would we do with “timing labels”?
    - Hard to prevent programs from “taking time”!
- But could IFC apply to timing channels too?

Adapting IFC to Timing Analysis

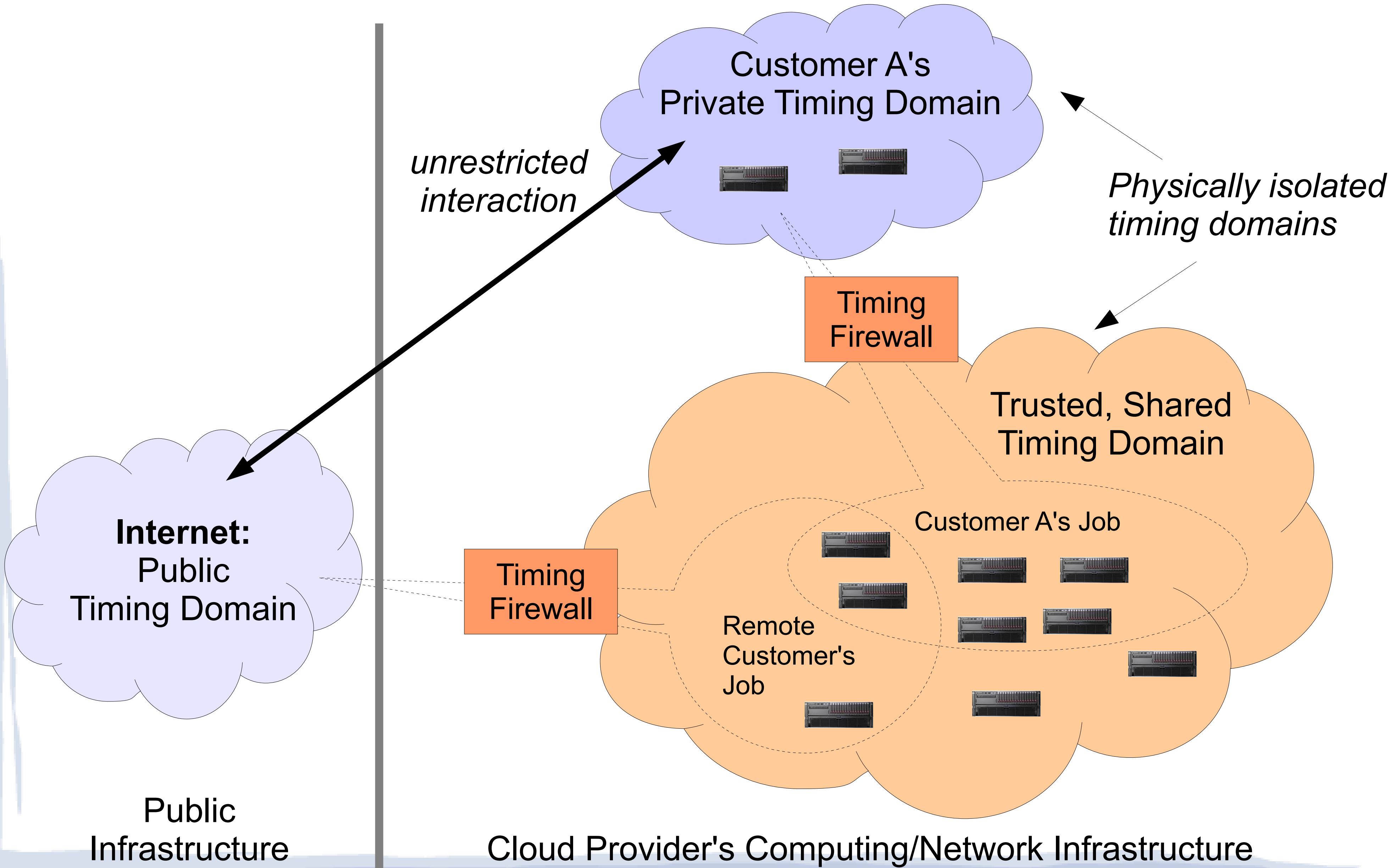
Key idea: we need two kinds of labels

- **State labels** attached to *explicit program state*
  - Represent ownership of information in the *bits* of a variable, message, process, etc.
- **Time Labels** attached to *event channels*
  - Represent ownership of information affecting *time* or *rate* events occur in a program

TIFC ≡ Timing Information Flow Control

- Analyze, constrain both state & timing leaks

A "Timing-Hardened Cloud"



Flume IFC Model

Flume IFC model summary:

- **Tags** represent ownership/taint: “Alice”, “Bob”
- **Labels** are *sets* of tags:
  - {Alice,Bob} $\equiv$ “contains Alice's & Bob's data”
- **Capabilities** enable adding/removing tags
  - e.g., If process P holds capability {Alice$^-$}, P can *declassify* (remove) the Alice tag

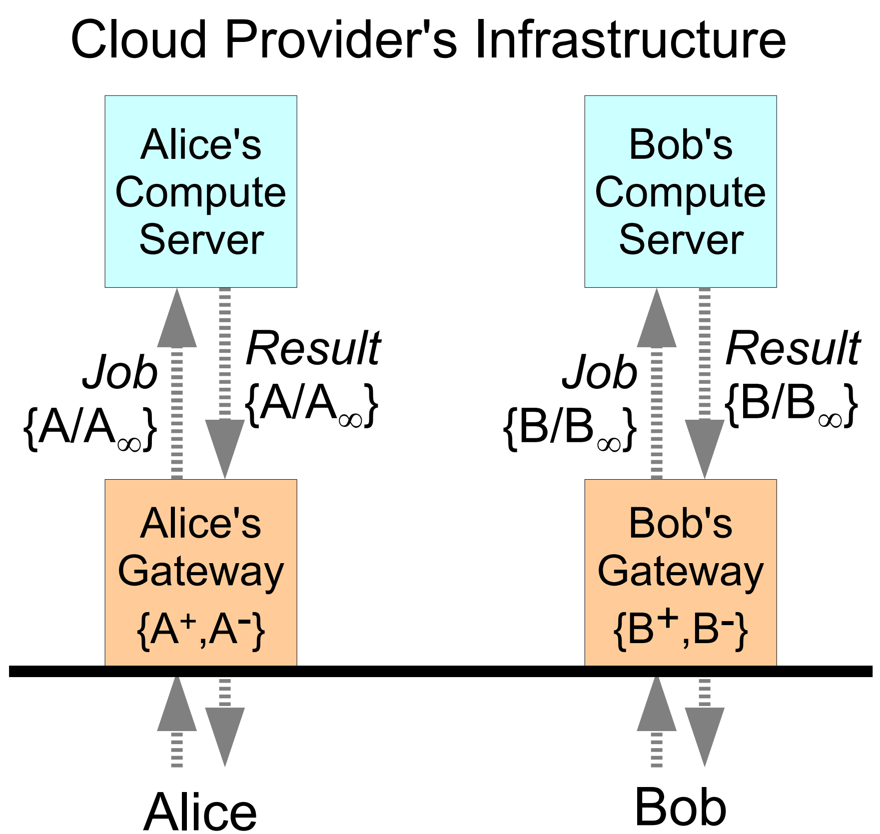
P can send data to Q iff $(L_P \setminus L_Q) \subseteq (C^-_P \cup C^+_Q)$

Adding Timings Labels to IFC

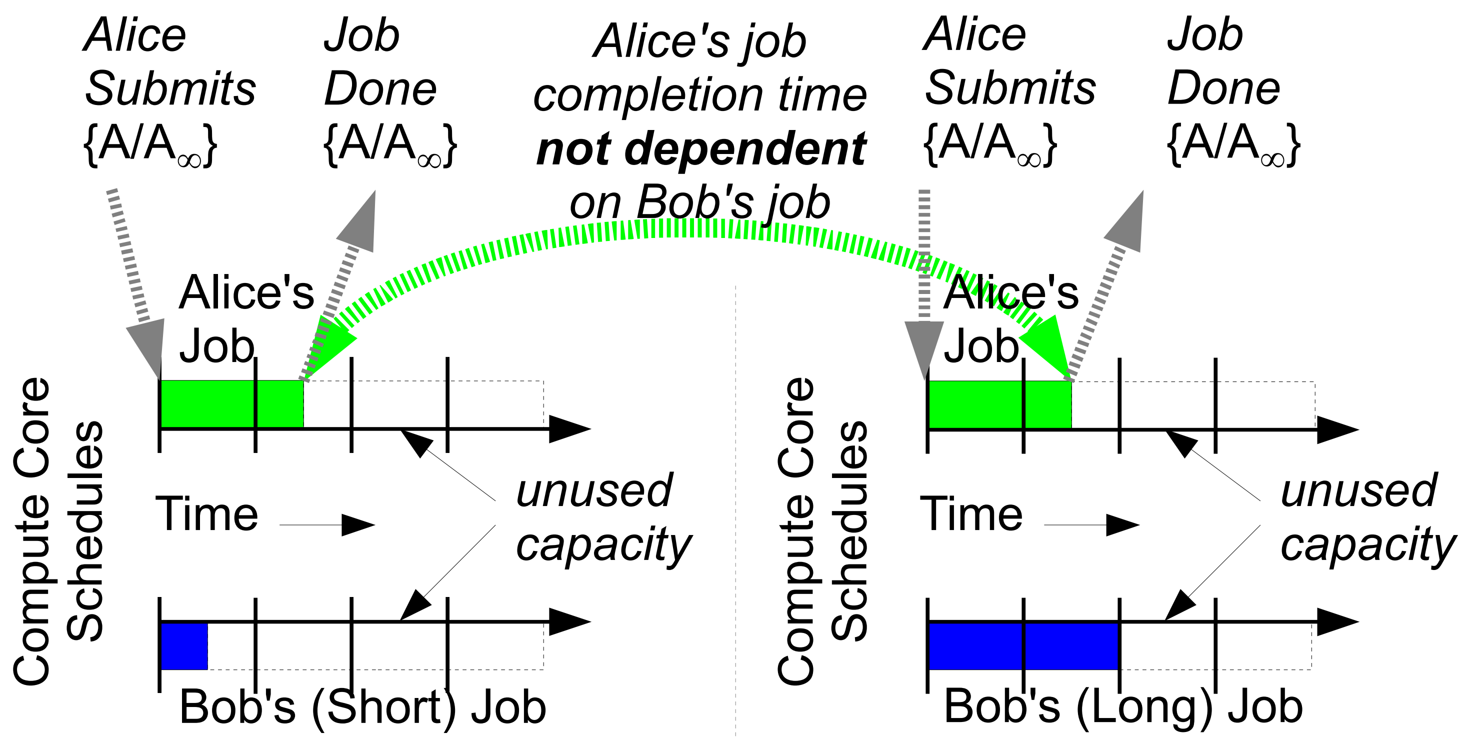
- **Timing Tag** is a tag with a frequency
  - Tag A_f indicates a timing channel might leak A's information at up to *f* bits per second
  - Tag A_∞ indicates a timing channel might leak A's information at arbitrarily high rate
- **Labels** can contain both state and timing tags
  - Message channel labeled $\{A/B_f\}$ indicates:
    - Message *bits* tained with A's info
    - Message *arrival events* in channel tainted by B's info at up to rate *f*

Example 1: Dedicated Resources

Trivial case: physical partitioning of resources

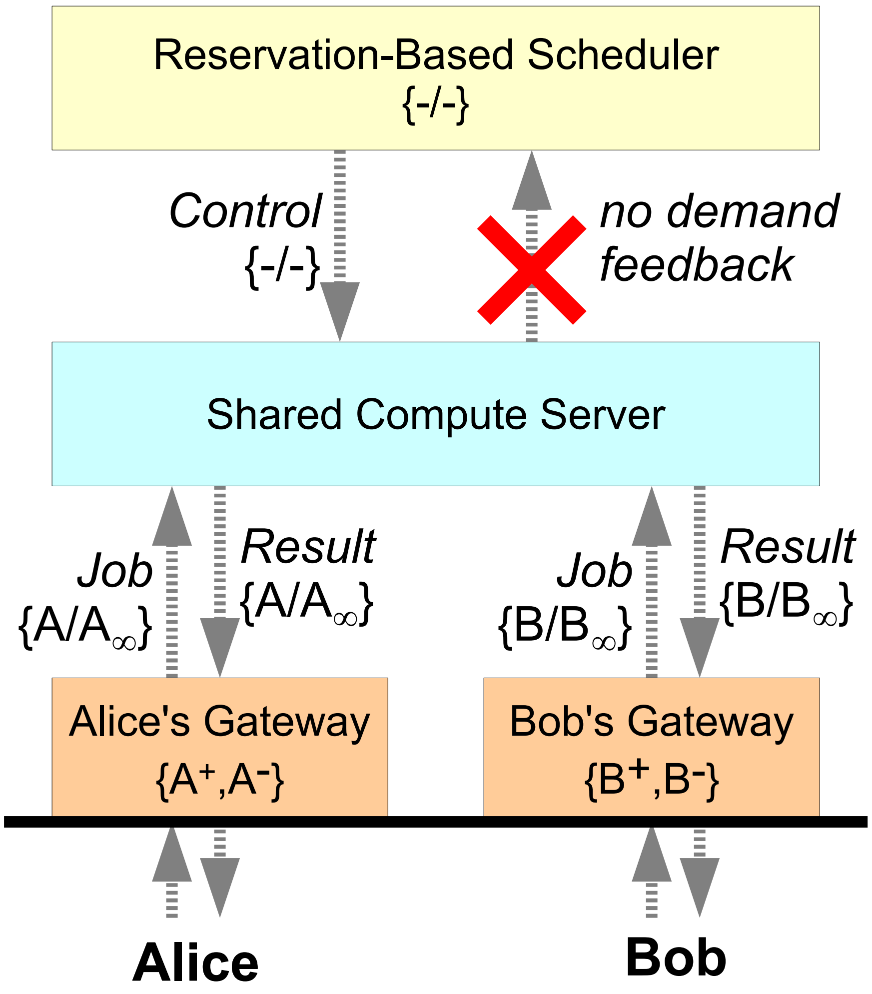


Informal "Schedule Analysis"

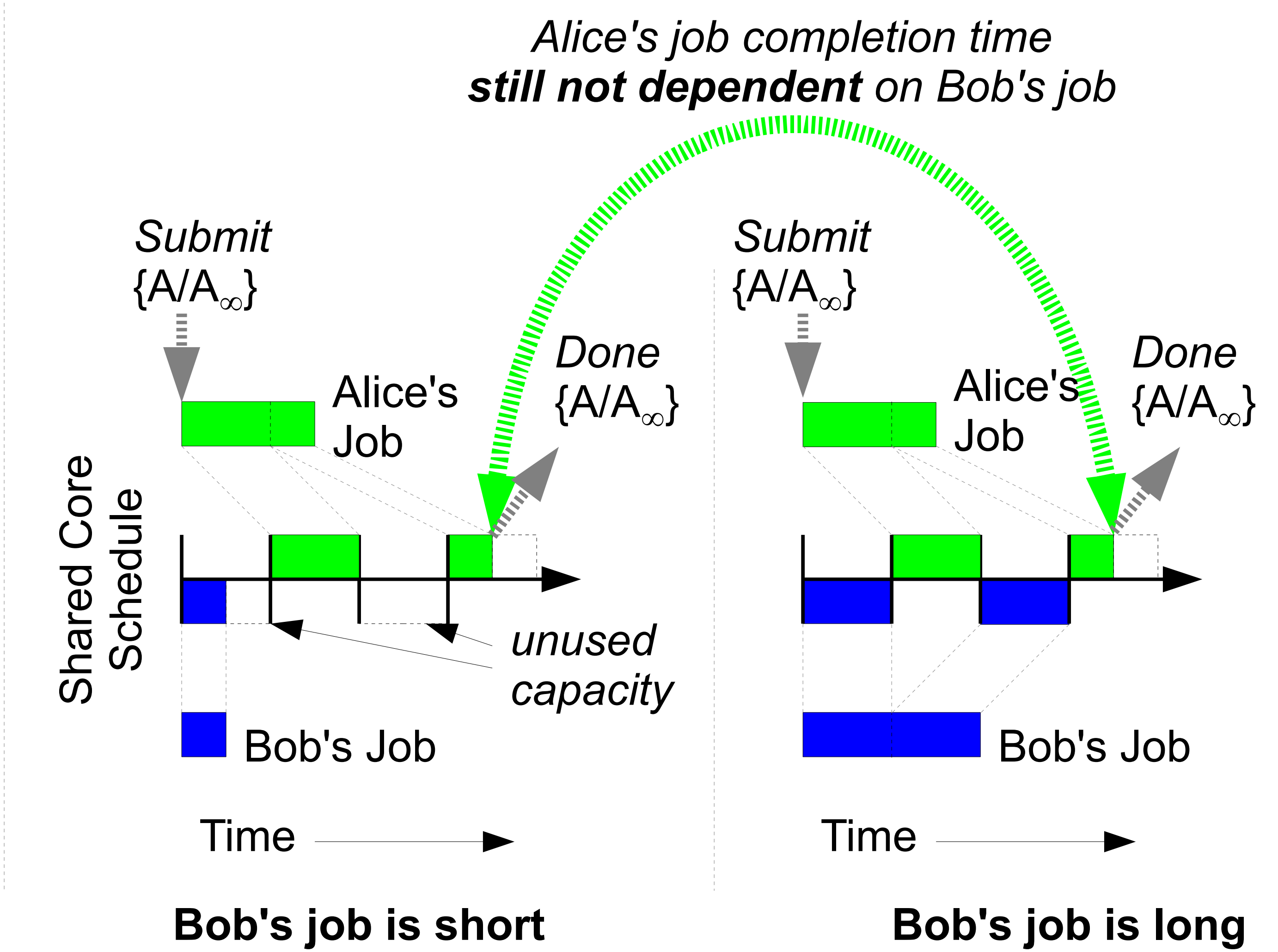


Bob's job is "short" **Bob's job is "long"**

Demand-Insensitive Timesharing



Informal "Schedule Analysis"

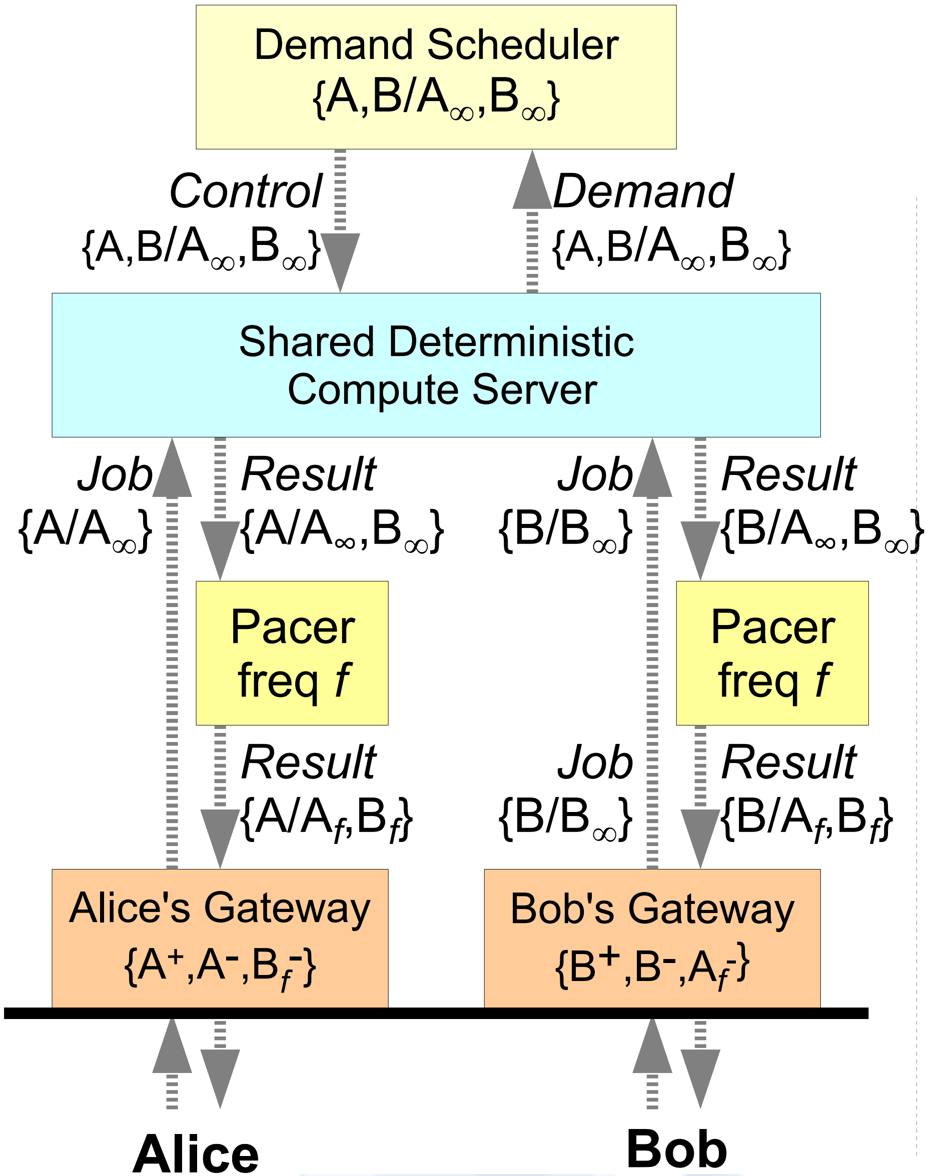


Timing Control in Elastic Clouds

Need two additional facilities:

- *System-enforced deterministic execution* [OSDI '10]
  - OS/VMM ensures that a job's outputs depend *only* on job's explicit inputs
- *Pacing queues*
  - Input jobs/messages at any rate
  - Output jobs/messages on a *fixed schedule*

Elastic Cloud Scenario

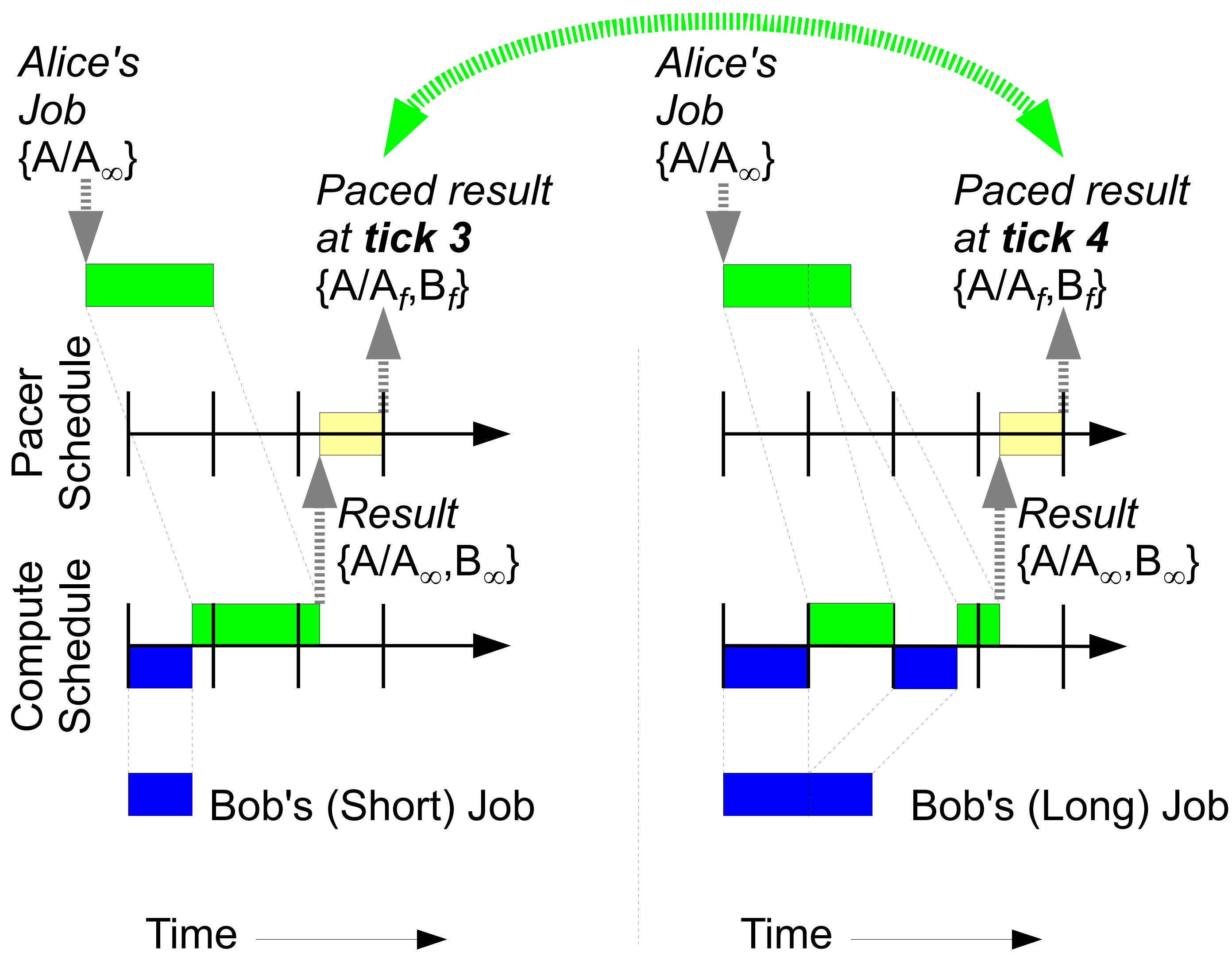


Jobs: In Anytime, Out on a Schedule

For each customer (e.g., Alice):

- Deterministic execution ensures job output *bits* depend only on job input *bits*: $O_j = f(I_j)$
- Job outputs produced *in same order* as inputs
- At each "clock tick", paced queue releases either ***next job output*** or says ***not ready yet***
  - The ***single bit of information*** per clock tick that might leak other users' information

Informal “Schedule Analysis”



(b) Schedule: Bob's job short **(b) Schedule: Bob's job long**

Key Challenges/Questions

- Formalize full TIFC model
  - Potentially applicable at systems or PL levels
  - Integrate Myers' “predictive mitigation” ideas
- Build TIFC-enforcing prototype
  - Ongoing, based on Determinator [OSDI '10]
- Explore flexibility, applicability of model
  - Can model support interactive applications?
  - Can model support transactional apps?

Conclusion

- TIFC = IFC extended to timing channels
- Several "timing-hardening" approaches
  - Physical partitioning
  - Demand-insensitive timesharing
  - Elastic computing via deterministic job model
- First general approach that could be both:
  - Feasible on unmodified hardware
  - Suitable for stat-muxed clouds

Further information: http://dedis.cs.yale.edu