Control Loops In Userspace

Google's Cluster Management Problems

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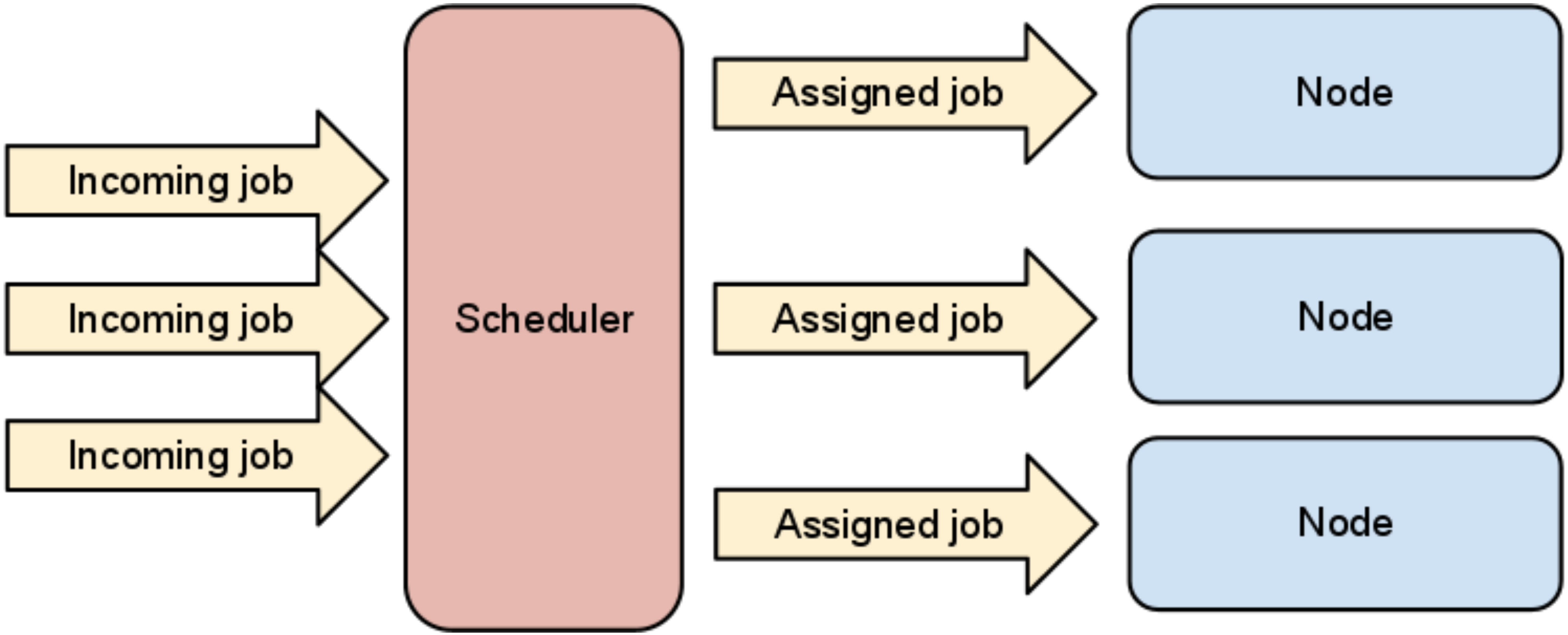
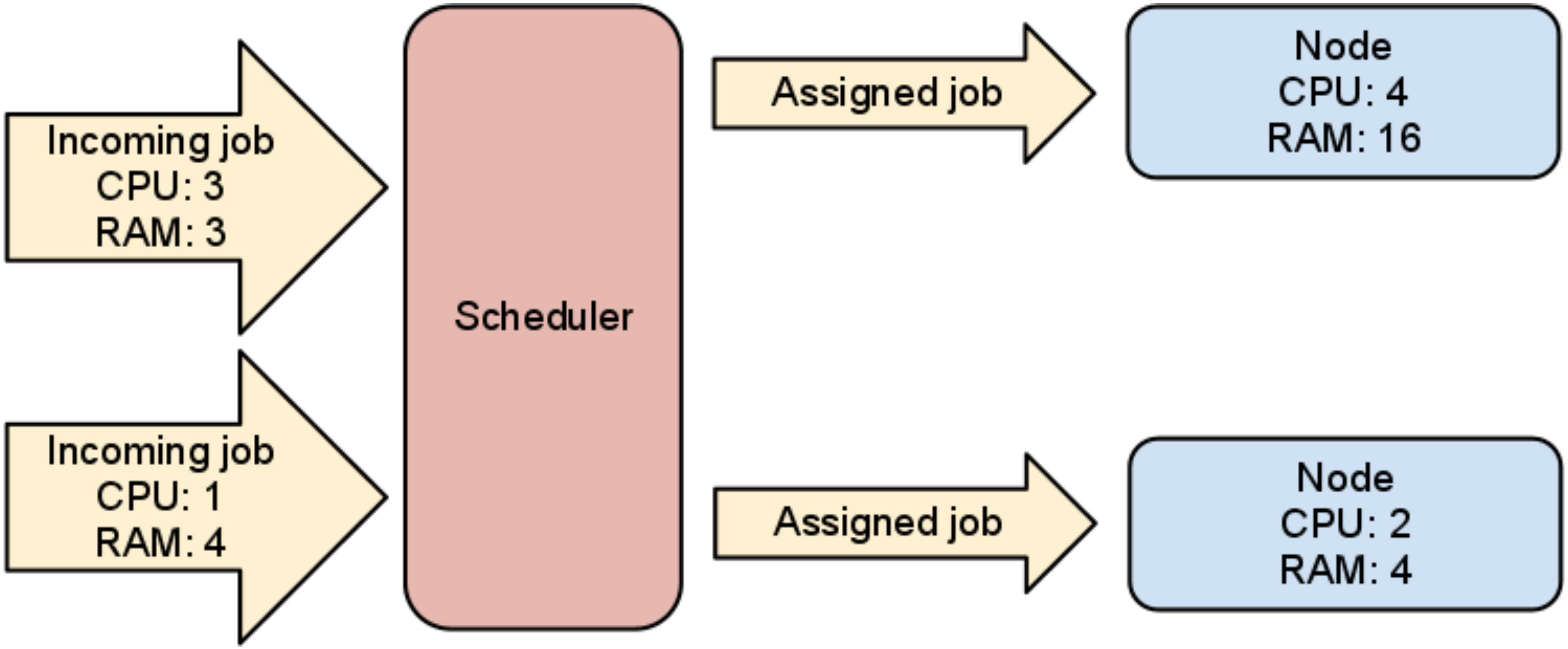
Overview


Incoming job
Incoming job
Incoming job
Scheduler
Assigned job
Assigned job
Assigned job
Node
Node
Node

Resources



Incoming job
CPU: 3
RAM: 3
Incoming job
CPU: 1
RAM: 4
Scheduler
Assigned job
Assigned job
Node
CPU: 4
RAM: 16
Node
CPU: 2
RAM: 4

Schedulable entities

- Task (with a capital T)
  - "Run me now"
  - Consumes node resources immediately
  - Can be stopped

- Alloc (with a capital A)
  - "Make room for me"
  - Consumes no node resources
  - Can be stopped
  - Can have multiple Tasks scheduled "inside"
  - Has "child" resources and "shared" resources

Utilization

- Tasks rarely use 100% of their resources
- Allocs are, by definition, place holders
- Result: overall utilization is low
- Why can't we run more stuff?
- Over-commit is dangerous - some tasks are clearly more important than others (e.g. web search vs a map reduce)
- If we want to do overcommit, we need to be able to react to dynamic load changes

User-facing semantics

- Important jobs get guaranteed resources. Other jobs get best-effort resources
- We call this "tier 1" and "tier 2"
- Tier 2 is "second hand" resources that we have already sold as tier 1, but are not currently being used
- Tier 2 Tasks might be killed at any moment, but on average are not
- Tier 1 resources cost a lot more than tier 2 resources
- We never over-commit tier 1 resources
- We can pack machines with tier 2 resources

Containers

- Tasks and Allocs exist in Containers
- Container != cgroup
- Container == {CPU rate, memory space, disk space, disk bandwidth, net bandwidth, TCP/UDP ports, chroot, ...}
- A Container is a **concept** that achieves our goals

Goals

- Isolation
  - Tasks should not impact each other
  - Behavior of a task should be the same regardless of what else is on the machine

- Predictability
  - Tasks should behave the same each time they run
  - Unless they are specifically configured to use "slack"

- Minimal impact
  - Tasks should not need to know about what we do behind the curtain

Managing over-committed machines

- We watch all running Tasks in near-realtime
- We only sell resources to account for the whole machine at any given time
- If a tier 1 Task has a load spike, a tier 2 Task might be killed to cover it
    - Some resources are "compressible" (CPU) and some are not (RAM)
- We have to react quickly!
- Kernel support is critical, but not always available

Mechanisms

- We like cgroups
  - Easily group tasks together for resource management
  - Easily apply userland policy to manage different resources
  - The kernel can react to conditions very quickly.
  - Need hierarchical cgroups

- We implement control loops in userspace when required
  - These hurt. Complex, racy, inaccurate.

- Other control APIs, e.g. disk quota, /proc/pid/maps, etc.

Real issues

- Memory containment
    - We use fake NUMA for this today
    - Pack pages onto as few nodes as possible
    - Practical limits to how many nodes we can have
    - Node size wastes RAM
    - Requires lots of userspace management
    - Moving to memory cgroup
        - Almost no control loops!
        - Need full hierarchy support
- Shared resource control
    - We manually re-balance CPU time in Allocs
        - Moving toward hierarchical cgroups
    - We manually re-distributed IO bandwidth in Allocs
        - Moving toward hierarchical cgroups

Real issues

- OOM management
  - We have to bring down whole Containers, rather than individual processes.
  - Today we have to trap OOM and do the work in userspace.

- Accounting of shared resources
  - Multiple Tasks in an Alloc map a disk-page. Who gets the bill? We want the Alloc to get billed. We do manual accounting.
  - Multiple unrelated Tasks map a disk-page. Who gets the bill? e.g. libc

Wishlist

- OOM killing for whole cgroups
- Deterministic shared-page billing
- Reduced overhead for cgroups (scalability)
- Hierarchical memory cgroups in all aspects
  - Per-cgroup reclaim based on soft-limit
  - Per-cgroup working-set estimates
- Proportional IO (dist time) hard limits
- Atomic signalling and/or killing of cgroups
- cgroup control of *any* shared resource
  - thread limits, fd limits, ports, network interfaces, etc
  - anything with a system-global limit or impact
- More OOM adjustment granularity
- Highly accurate stats, e.g. wakeup times, per sched_entity
- Backend billing for things like interrupts
- Cache isolation
- Memory and cache bandwidth stats