Project Orleans
Distributed Virtual Actors for Programmability and Scalability

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Project “Orleans” is a programming model and runtime for building *cloud native* services

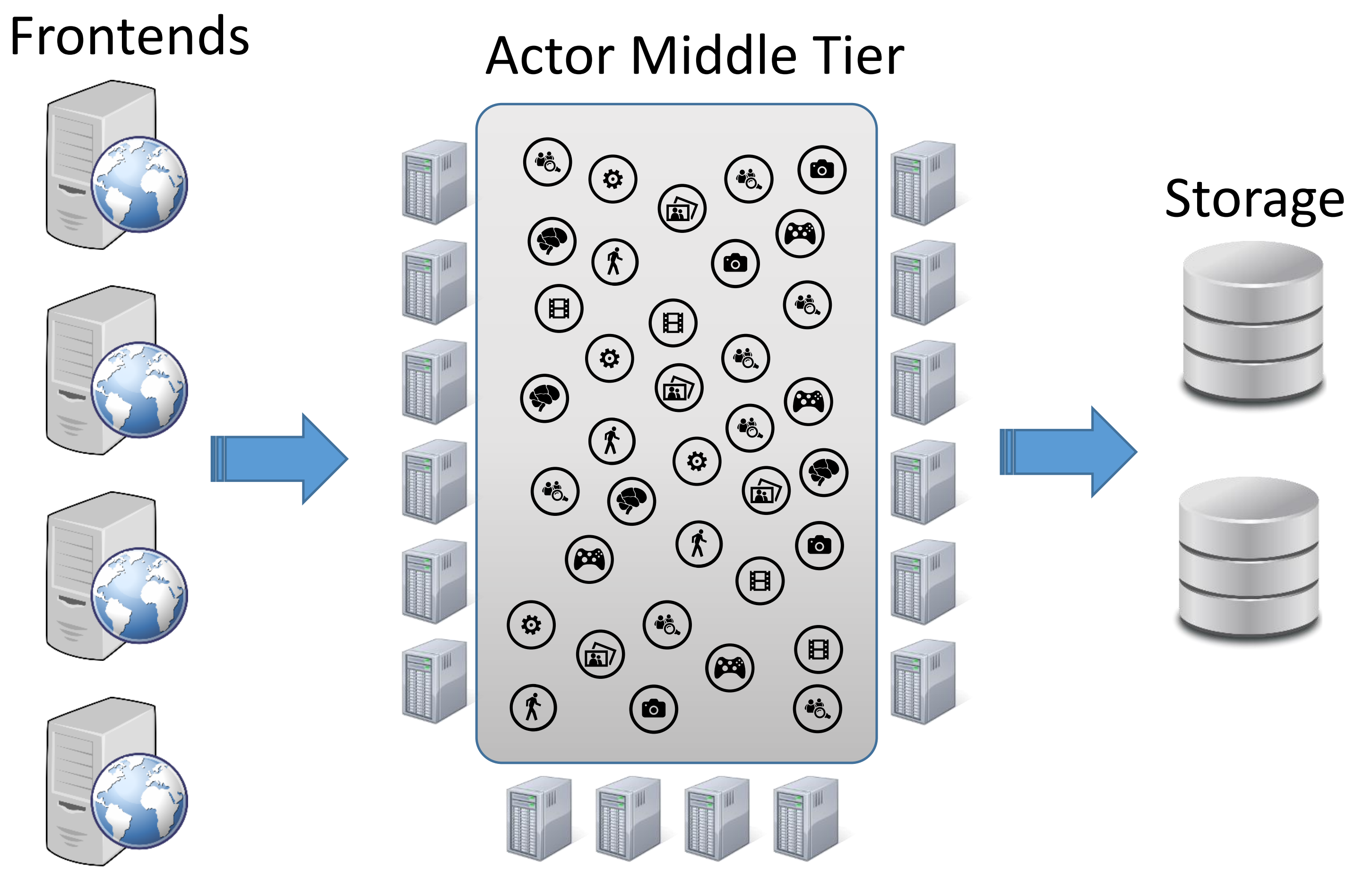
What is Project “Orleans”?

- Oversimplifying it: “Distributed C#”
  - Orleans runs your .NET objects on a cluster as if within a single process
  - Define .NET interfaces and classes, deploy to Azure, send requests to them
- Practically: “Toolset for building cloud-native services”
  - Encapsulates best practices for building scalable, reliable, elastic services
  - Framework for stateful near-real-time backends
  - 3-5x less and simpler code to write, scalability by default
- Academically: “Distributed virtual actor model”
  - Adaptation of the Actor Model for challenges of the Cloud
  - Actors that exist eternally and never fail

Motivation

- Developer Productivity
  - Concurrency, distribution, fault tolerance, resource management…
  - Modern workloads are even ‘worse’
  - Domain of distributed systems experts
  - Help desktop developers [and experts] succeed
  - *Write less code*
- Scalability by default
  - Designs and architectures break at scale
  - Failure to scale may be fatal for business
  - Code must be scale-proof – must scale out without rewriting

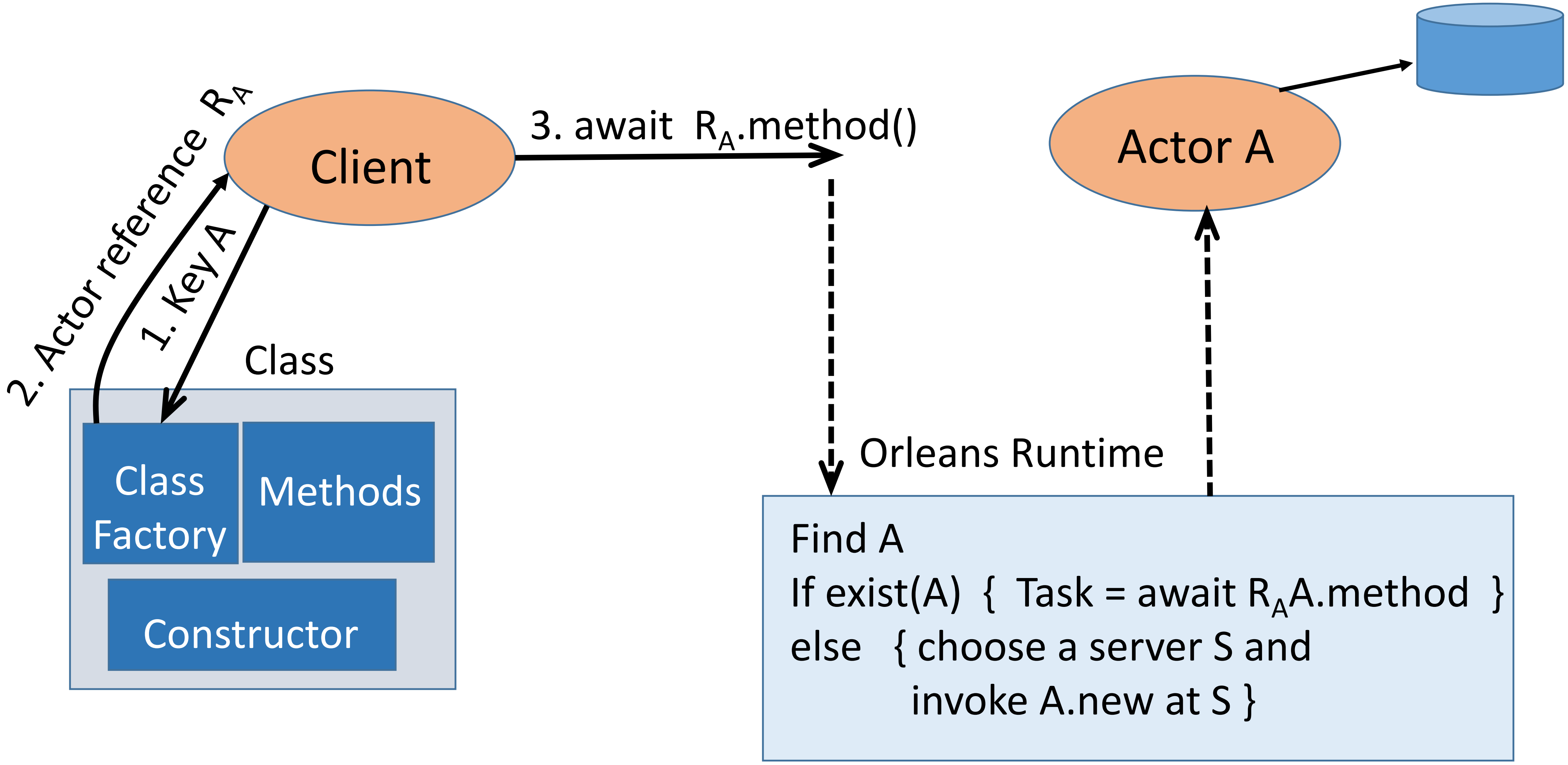
Actor Model as Stateful Middle Tier



Orleans Programming Model

- Each class has a key, whose values identify instances
  - Game, player, phone, device, scoreboard, location, etc.
- To invoke an actor A, the caller passes the key to its local class factory and gets back an actor reference R_A
- The actor invokes a method on R_A
- Method invocations are asynchronous
  - Return a “task” (i.e., a promise)
  - An attempt to reference a task’s result blocks the caller until the task completes
  - .NET has language support for this (Task-Await)

Invoking a method on actor A



Key Innovation: *Virtual* actors

1. Actor instances always exist, virtually
    - Application neither creates nor deletes them. They never fail.
    - Code can always call methods on an actor
2. Activations are created on-demand
    - If there is no existing activation, a message sent to it triggers instantiation
    - Transparent recovery from server failures
    - Lifecycle is managed by the runtime
    - Runtime can create multiple activations of stateless actors (for performance)
3. Location transparency
    - Actors can pass around references to one another or persist them
    - These are logical (virtual) references, always valid, not tied to a specific activation

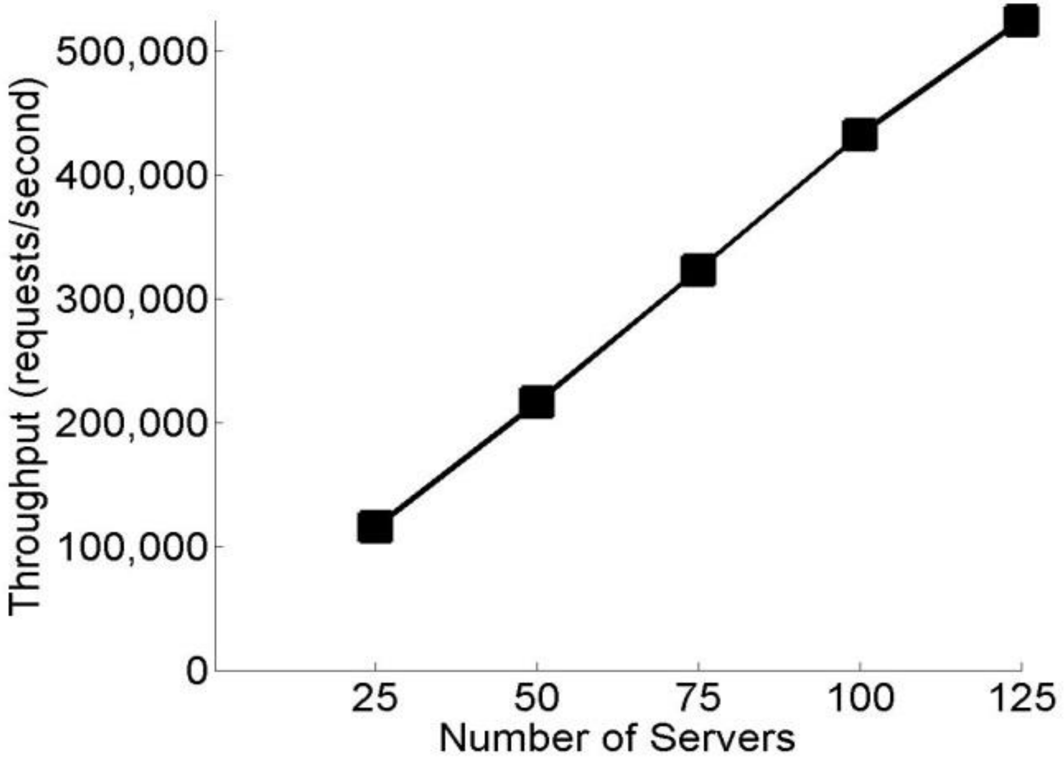
Actor State Management

- The runtime instantiates an actor by invoking the actor’s constructor
  - The constructor typically reads the actor’s state based on its key
  - Usually from storage, but possibly from a device (e.g. phone, game console, sensor)
- The actor saves its state to storage whenever it wants
  - Typically before returning from a method call that mutates its state
  - Or could be after *n* seconds, or after *n* calls, etc.
- Orleans does not support transactions (yet)
- Declarative persistence
  - Attach all state variables to an interface that inherits from IState
  - Declare a persistence provider for the class (Azure Table, Azure SQL DB, Redis…)
  - Invoke “WriteState” to save the state to the persistent store

Scalability

- Near linear scaling to hundreds of thousands of requests per second
- Also scalable in number of actors
- Multiplexed resources for efficiency
- Location transparency simplifies scaling up or down
- Elastic – transparently adjusts to adding or removing servers

Test Lab Numbers



Request: Client → Actor 1 → Actor 2

Orleans was built for…

Scenarios

- Social graphs
- Mobile backend
- Internet of things
- Real-time analytics
- ‘Intelligent’ cache
- Interactive entertainment

Common characteristics

- Large numbers of independent actors
- Free-form relations between actors
- High throughput/low latency
- Fine-grained partitioning is natural
- Cloud-based scale-out & elasticity
- Broad range of developer experience

- Not good for a service where different requests span different combinations of records over a large database

Other features

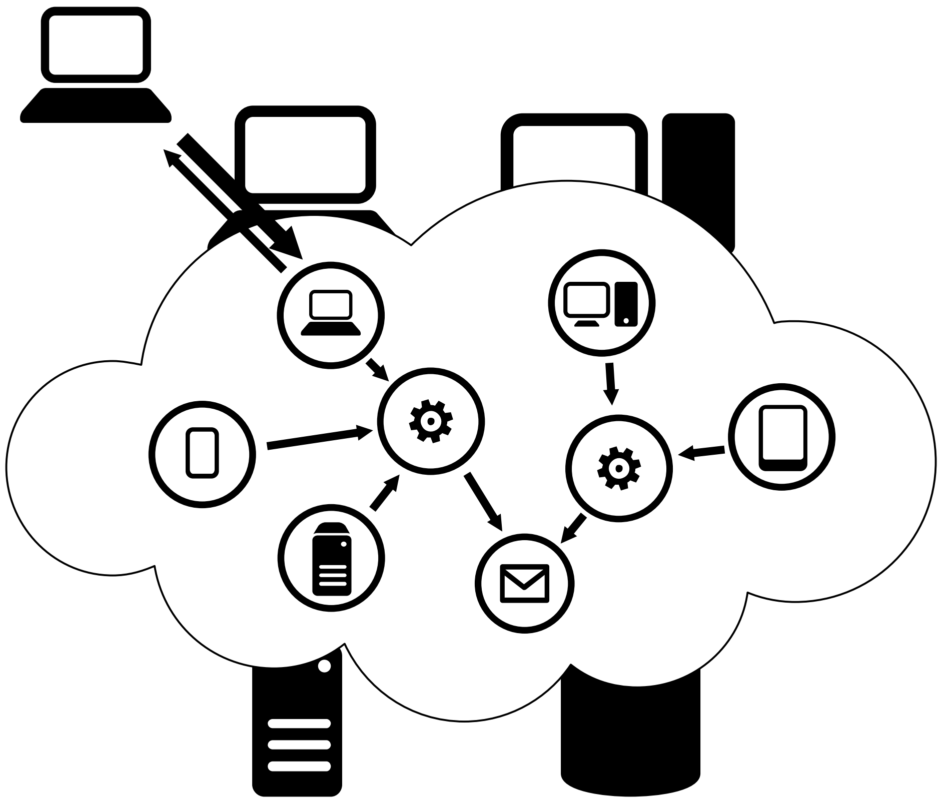
- Exceptions are automatically propagated
- Timers that live as long as the hosting activation
- Fault-tolerant timers, for infrequent events

Production usage

- Halo 4 - all back end services
  - Players, games, weapon caches, regions, scoreboards, ….
  - Dozens of services, 10s to 100s of machines each
  - 100Ks of requests per second
  - Bursty load (evenings, weekends) and peak load at product launch
- Back end services of many other game studios
- About ten other Microsoft services run on Orleans
  - Examples: intelligent cache, telemetry.
- Public preview since April 2014

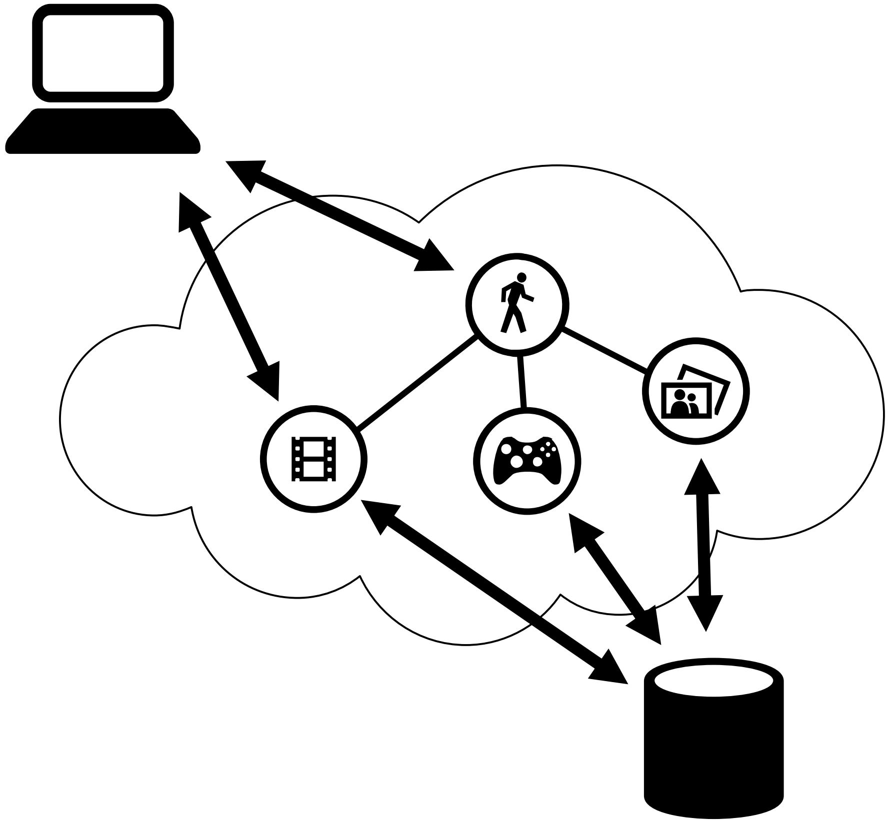
Near real-time analytics

- Devices send telemetry to the Cloud
- Per-device actors process and pre-aggregate incoming data
- Grouping by location, category, etc.
- Statistics, predictive analytics, fraud detection, etc.
- Control channel back to devices
- Elastically scales with number of devices and groupings



Intelligent cache

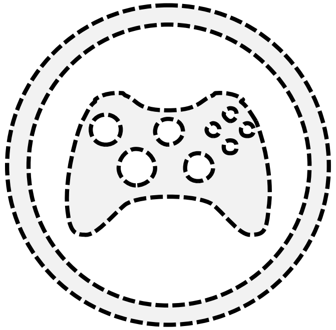
- Actors hold cache values
- Semantic operations on values
- Function shipping (method calls)
- Coordination across multiple values
- Automatic LRU eviction
- Transparent on-demand reactivation
- Write-through cache with optional batching



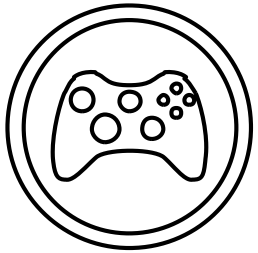
Outline

- ✓Orleans Overview
- Runtime Library
- Cluster Membership
- Actor Directory

Actors in Orleans

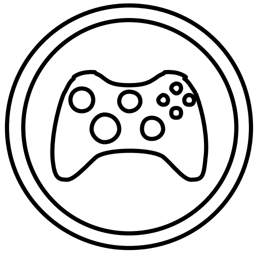


Game Actor Type



Game Actor (Instance)
#2,548,308

Game Actor #2,548,308
Activation #1 @ 192.168.1.1



Game Actor (Instance)
#2,031,769

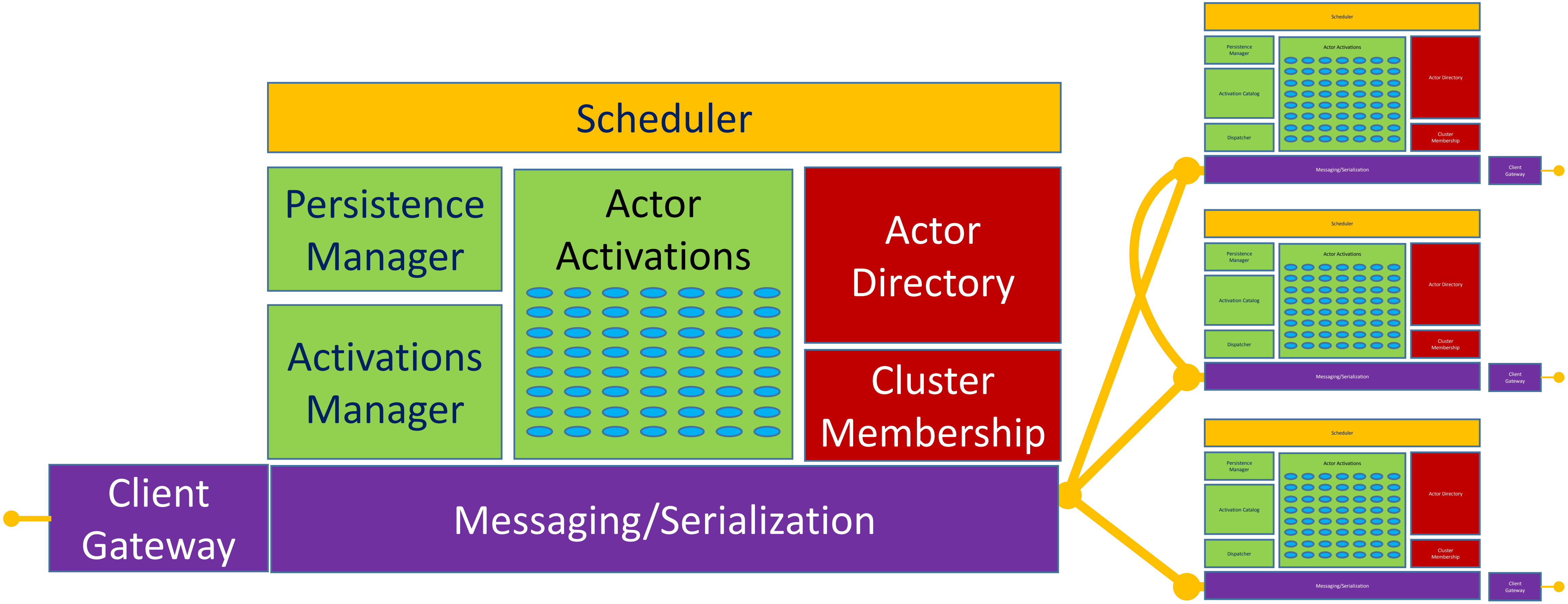
Game Actor #2,031,769
Activation #1 @ 192.168.1.5

Actor Type | **Actor (Instance)** | **Actor Activation**

Actor execution model

- Activations are single-threaded
  - Optionally re-entrant
  - Runtime schedules execution of methods
  - Multiplexed across threads
- No shared state
  - Avoid races
  - No need for locks
- Cooperative multitasking
  - Everything must be asynchronous

Distributed Runtime



Achieving Efficiency and Scalability

- Cooperative multitasking
- Multiplexed Communication
- Balanced placement
- Custom Serialization
- Support for Immutability

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Cluster Membership

- A <u>cluster</u> is a set of servers
- Each server must know the identity of every other available server in its cluster
- Orleans uses reliable storage to store the consensus view
  - A table, with one row per server describing the server's state
- We use Microsoft Azure Table service
  - Supports optimistic concurrency control via http ETags.
    Read returns a row's ETag.
    Write only if the row's ETag is unchanged.
  - Supports transactions over rows with the same partition key

Cluster membership protocol

- The servers form a ring using consistent hashing
- Each server pings the next 3 in the ring, every few seconds.
- If a server S gets N successive failures to ping server T,
  S writes its timestamped suspicion into T’s row
- If T has more than M suspicions within K seconds, then
  - S writes that T is dead into T’s row, using an Etag to avoid lost updates
  - and broadcasts a request for all servers to re-read the membership table (which they’ll do anyway periodically)
- T kills itself upon learning it is dead.
  System infrastructure will restart it with a new name

It’s useful to totally order membership states

- Avoids two servers killing two other servers, and neither of them knowing right away about the other one’s actions.
- Serializes the joining of new servers to the cluster
  - Allows a new joining server to validate two-way connectivity to every other server that has already started.
  - Ensures that at least when a server starts, there is full connectivity between all servers in the cluster.

Totally ordering membership states

- So we add a membership-version row that tracks state changes
- Within a transaction, S writes that T is dead and,
  if S's membership-version is still fresh, S increments the version number in the membership-version row, else S aborts.
  - If S's membership-version was stale, it re-reads the membership state and re-runs the transaction
- That way the membership configurations are totally ordered with increasing version number

Algorithm properties

- Our algorithm can handle any number of failures.
  - I.e., does not require quorum.
  - We have seen production situations when over half of the servers were down.

- Our algorithm can handle thousands and probably even tens of thousands of servers
  - Paxos-based solutions generally do not scale beyond tens of servers

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Actor Directory: ActorID → ServerID

- Stored in a DHT, spread across all active servers
- Each server owns a partition of the key space
- Each actor is assigned to a partition by consistent hashing
- Directory enforces the single-activation constraint
- Each server caches recently used actor-to-server mappings
- A mapping entry can be wrong (stale cache, failed unregister)
  - Recipient of a misdirected message reroutes it or returns an exception
  - Sender and receiver correct the error by invalidating a cache entry or updating the directory entry

Server failures

- When a server F fails, its directory partition is lost
- When server S_1 learns of F's failure
  - It purges its directory partition of actor entries that map to F
  - It kills local actor activations that were mapped by F
- While resolving a failure, the directory might be inconsistent
  - We favor availability over consistency
  - This "eventual single-activation consistency" semantics has been the right tradeoff for most applications

Eventual single-activation consistency

- Single instancing may be compromised during recovery
  - Suppose actor α was mapped by F to server S_2
  - If S_2 is slow at learning of F's failure, a server with a cached entry for α may invoke α at S_2
  - Meanwhile, if S_1 invokes α, it will create a new directory entry for it at (say) server S_3 and activate it at (say) S_4

  ☹ So now there are two activations of α, at S_2 and at S_4
- Eventually, S_2 will learn of F's failure and kill α
  - α at S_2 might save its state during its rundown, which might conflict with state saved by α at S_4
  - If so, α at S_2 will have to merge its state with the one saved by α at S_4

Geo-distributed Actor Directory (prototype)

- Suppose an application is distributed in many clusters
- To ensure single-instancing, a request to activate actor α in cluster C_1 triggers a consensus protocol with other clusters
  - C_1 asks other clusters if they have a copy.
  - If all clusters reply “no”, then C_1 can safely instantiate α
  - If C_2 says “yes” at server SC_2, then C_1 maps α to SC_2
  - If a cluster C_3 doesn’t reply, then C_1 instantiates α anyway, favoring availability over consistency
- Optimistic consensus: instantiate α and then run consensus, if it’s very unlikely another cluster will instantiate α.
- When C_3 reunites with C_1, they run a reconciliation protocol for actors they created when they were disconnected.

Geo-distributed directory reconciliation

- When server membership changes, servers exchange lists of in-doubt actors.
- If ≥ 2 servers have instantiated an actor with at least one in-doubt
  - Then use a fixed precedence relation over server ID's to choose a winner.
  - Precedence could be global, per class, or per class+key

Conclusion

- Orleans Benefits
  - Significantly improved developer productivity
  - Makes cloud-scale programming attainable to desktop developers
  - Scalability by default. Excellent performance
  - Proven in multiple production services
- Main innovation: Virtual actor programming model
- Runtime algorithms
  - Cluster membership
  - Actor Directory
- Future work: transactions, streams, dynamic optimization

Website
http://research.microsoft.com/en-us/projects/orleans/

Get the public Community Preview:
http://aka.ms/orleans

Get the Samples:
https://orleans.codeplex.com/

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