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

1. Key A
2. Actor reference $R_A$
3. await $R_A$.method()

Client

Actor A

Orleans Runtime

Find A
If exist(A) { Task = await $R_A.A$.method }
else { choose a server S and invoke A.new at S }
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

<table>
<thead>
<tr>
<th>Number of Servers</th>
<th>Throughput (requests/second)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>100,000</td>
</tr>
<tr>
<td>50</td>
<td>200,000</td>
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<tr>
<td>75</td>
<td>300,000</td>
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<tr>
<td>100</td>
<td>400,000</td>
</tr>
<tr>
<td>125</td>
<td>500,000</td>
</tr>
</tbody>
</table>

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

Actor Type

Game Actor Type

Game Actor (Instance)
#2,548,308
Activation #1 @ 192.168.1.1

Game Actor (Instance)
#2,031,769
Activation #1 @ 192.168.1.5
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

Scheduler

Persistence Manager
Actor Activations
Actor Directory
Cluster Membership

Client Gateway
Messaging/Serialization
Achieving Efficiency and Scalability

• Cooperative multitasking
• Multiplexed Communication
• Balanced placement
• Custom Serialization
• Support for Immutability
Outline

✓ Orleans Overview
✓ Runtime Library
• Cluster Membership
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Cluster Membership

- A **cluster** 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
Outline

✓ Orleans Overview
✓ Runtime Library
✓ Cluster Membership
  • Actor Directory
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 S₂
  • If S₂ is slow at learning of F’s failure, a server with a cached entry for α may invoke α at S₂
  • Meanwhile, if S₁ invokes α, it will create a new directory entry for it at (say) server S₃ and activate it at (say) S₄
    🤕 So now there are two activations of α, at S₂ and at S₄

• Eventually, S₂ will learn of F’s failure and kill α
  • α at S₂ might save its state during its rundown, which might conflict with state saved by α at S₄
  • If so, α at S₂ will have to merge its state with the one saved by α at S₄
Geo-distributed Actor Directory (prototype)

• Suppose an application is distributed in many clusters
• To ensure single-instancing, a request to activate actor $\alpha$ 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 $\alpha$
  • If $C_2$ says “yes” at server $SC_2$, then $C_1$ maps $\alpha$ to $SC_2$
  • If a cluster $C_3$ doesn’t reply, then $C_1$ instantiates $\alpha$ anyway, favoring availability over consistency
• Optimistic consensus: instantiate $\alpha$ and then run consensus, if it’s very unlikely another cluster will instantiate $\alpha$.
• 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

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

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