Stream Processing in an Actor-Oriented Database System

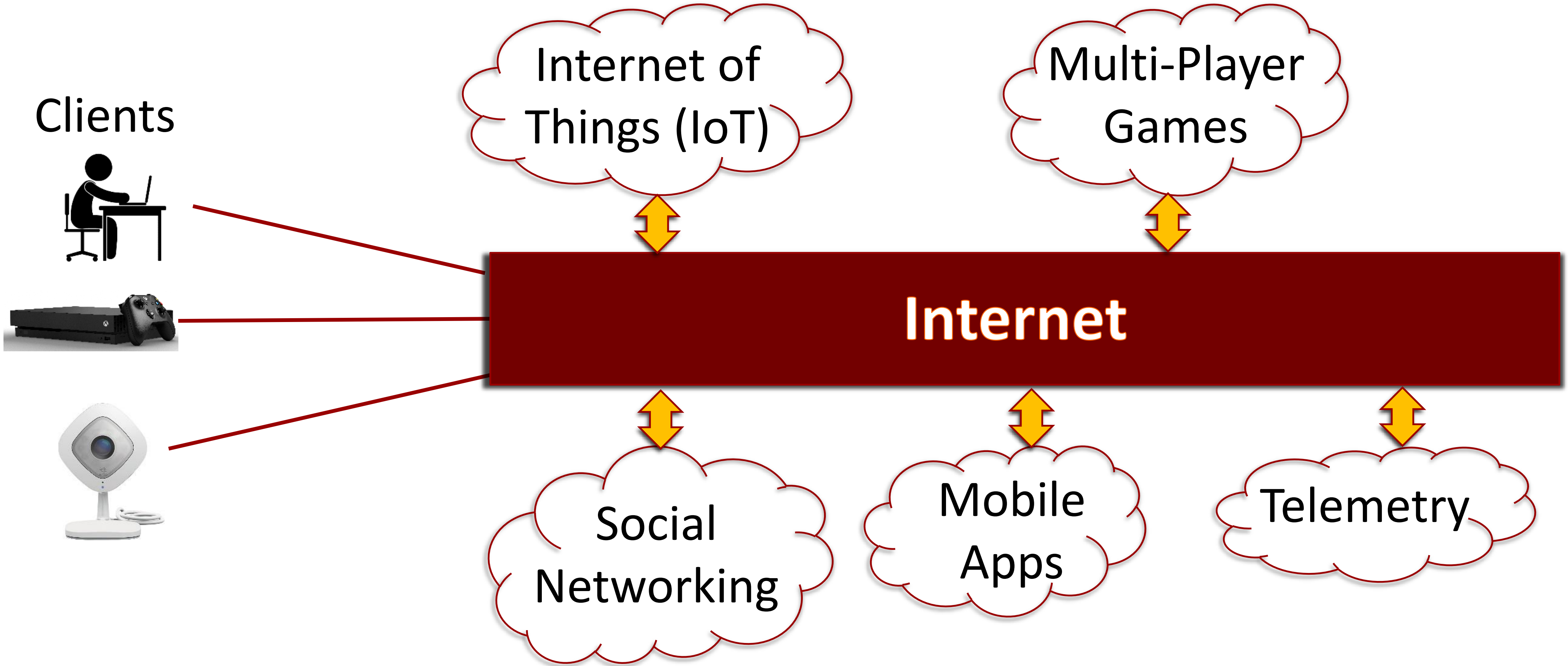
Philip Bernstein
Microsoft Research

BIRTE 2019
August 26, 2019

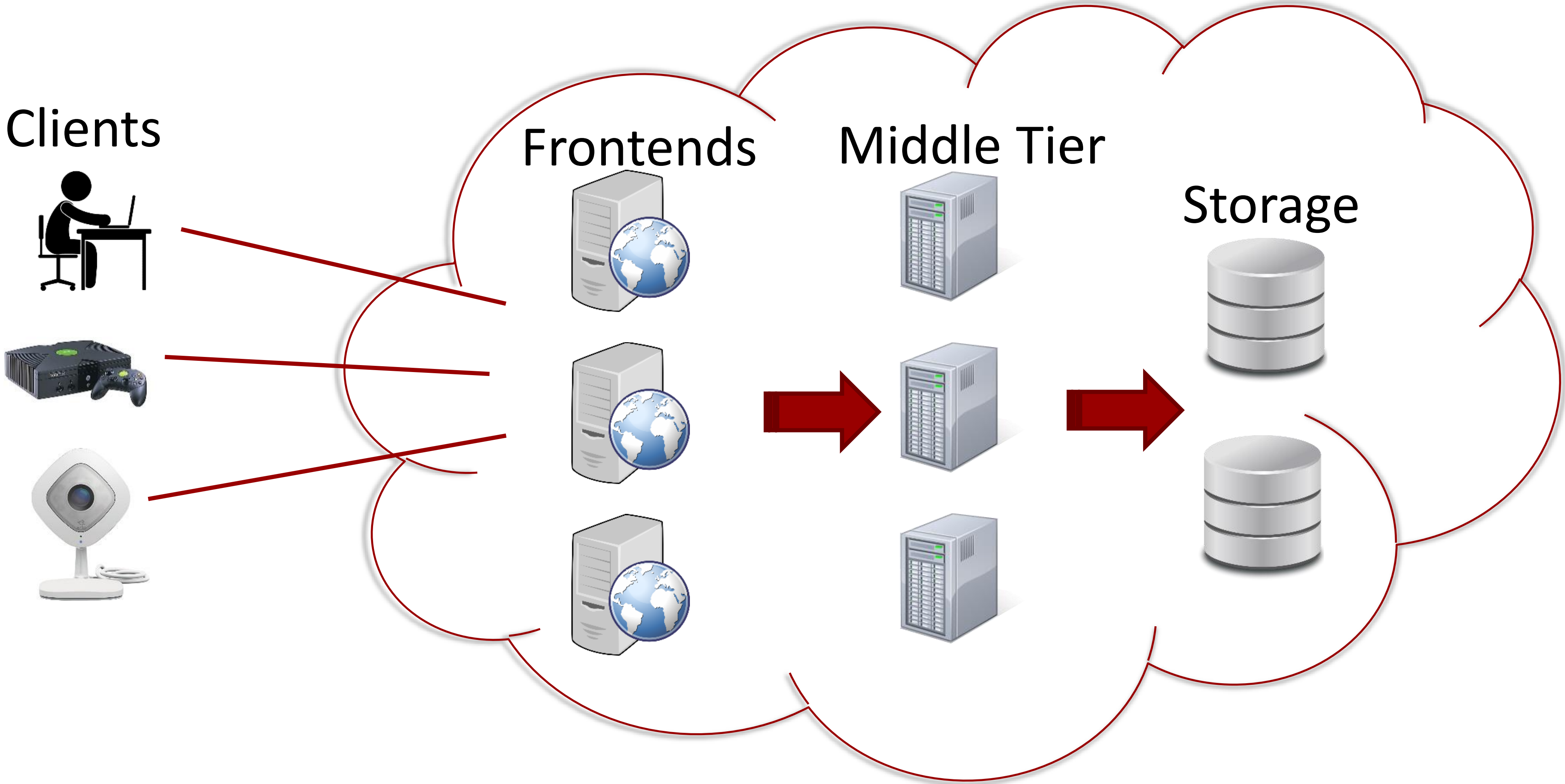
Outline

- Most new interactive services are stateful, object-oriented middle-tier applications
- They need database technology, but are currently poorly served
- One such technology is stream processing

Interactive Application Services



What's a Middle Tier?



Stateful Object-Oriented Applications

- These applications manage state, usually represented as objects
  - Naturally object-oriented, modeling real-world objects
- Examples of objects
  - Gaming: players, games, grid positions, lobbies, player profiles, leaderboards, in-game money, and weapon caches
  - Social: chat rooms, messages, photos, and news items
  - IoT: thermometers, motion detectors, cameras, GPS receivers, and virtual sensors built on top (room presence, traffic jams)

Scenario

- Player logs into game console
- Console connects to cloud service, creating Player object
- Player object connects to a Game-Lobby object
- Game-Lobby runs an algorithm to group players into a Game
  - Returns a reference to the Game object to all players
- Game object reports activities as a stream of events
- Game object writes to Scoreboard object
  - At the end, it might update the Leaderboard

Stateful Micro-Services

- Many micro-services execute stateful middle-tier OO apps
  - Data ingestion – event streams for real-time analytics
  - Workflow – manage long-running multi-step jobs
  - Smart contracts – workflows on blockchains
- Example – merge event streams from 100K servers
  - Index them, store them in batches, run continuous queries, publish query results to dashboards
- These services aren’t *naturally* object-oriented
  - But for scalability, OO is a good design approach

Application Properties

- Objects are **active for minutes to days**, sometimes forever
- App manages **millions of objects**, streams, images, and videos, and huge knowledge graphs
- App does **heavy computation**: complex actions, image rendering, continuous queries, computations over graphs, …
- App does **heavy communication**: high-bandwidth message streams

System Properties

- Service is highly available
- Compute, storage, and communications must scale out independently
- That’s why the three-tier architecture is popular

Actor Systems

- Many of these apps are implemented using an **actor system**
  - Greatly simplifies distributed programming
- Actors are objects that …
- Communicate only via asynchronous message-passing
  - Messages are queued in the recipient's mailbox
  - No shared-memory state between actors
- Process one message at a time
  - No multi-threaded execution inside an actor

ERLANG

akka

Orleans

Orleans Actor Programming Framework

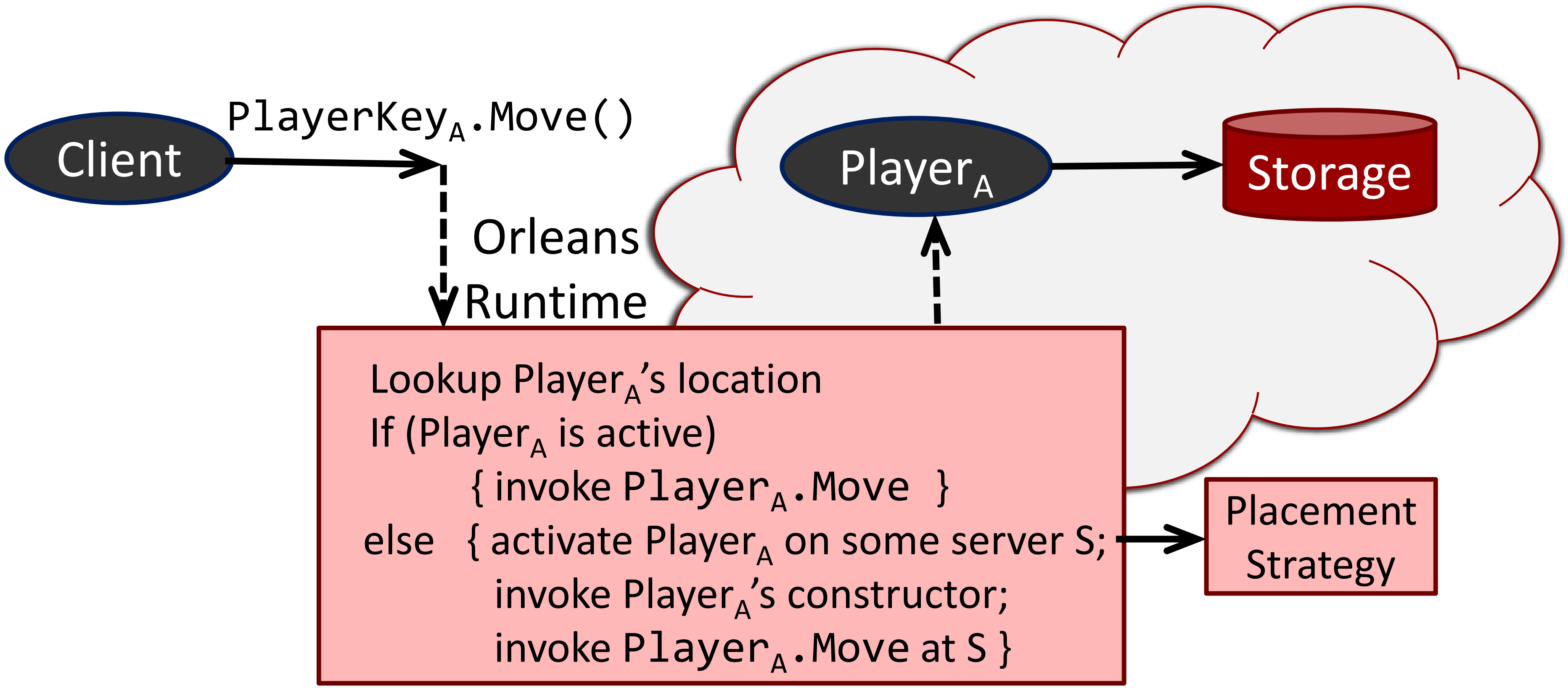
Orleans

- Orleans is an open-source actor framework in C#
  - https://dotnet.github.io/orleans/
- Invented the Virtual Actor model
  - Like virtual memory, actors are loaded and activated on demand
  - Deactivated after an idle period
- Supports scalability by load-balancing objects across servers
- Supports fault-tolerance by automatically reactivating failed objects

Orleans Programming Model

- Object is fully-encapsulated and single-threaded
- Each class has a key, whose values identify instances
  - Game, player, phone, device, scoreboard, input stream, workflow, etc.
- Asynchronous RPC
  - `Key.Method(params)` returns a "task" (i.e., a promise)
  - "`Await Task`" blocks the caller until the task completes
  - .NET has language support for this (`Async-Await`)

Calling an Actor's Method



Orleans magic: A fault-tolerant DHT maps object-ID to server-ID

Fault Tolerance

- Object can save state at any time, e.g., to storage
- Runtime automates fault-tolerance

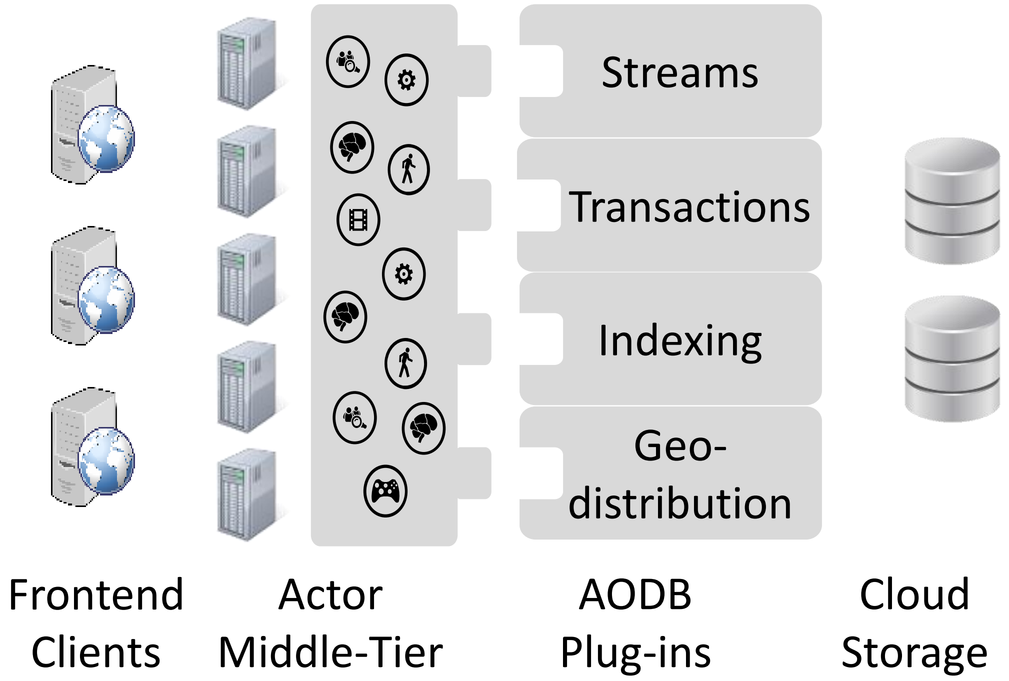
```
public class Account
{
  int balance;

  Task async Withdraw(int x)
    { if (balance >= x)
         { balance = balance – x;
           Save State;
           return 1; }
      else return 0;
    }
}
```

Good news / Bad news

- Good news
  - The virtual actor model automates scalability and fault tolerance
- Bad news
  - App is responsible for managing its state
- Let's treat the app as a database of objects
  - Offer standard database abstractions

Actor-Oriented Database System (AODB)

- Indexes
- Transactions
- Queries
- Views
- Triggers
- Replication
- Geo-distribution
- Streams



Examples

- Transaction – Player X buys a kryptonite shield
- Index – Get all players in Los Angeles
- Query – Get all players in L.A. who are playing Halo with ≥ 8 other players
- View – the number of active instances of each game
- Trigger – notify a chess player when it's his/her move
- Stream – Watch player actions, looking cheaters

Actor-Oriented Database (AODB) Unique Requirement

- Storage independent, using cloud storage
- In particular, stream-transport independent. It should work with
  - Azure Event Hubs
  - Azure ServiceBus
  - Azure Queues
  - Apache Kafka
  - TCP/IP messages
  - . . .

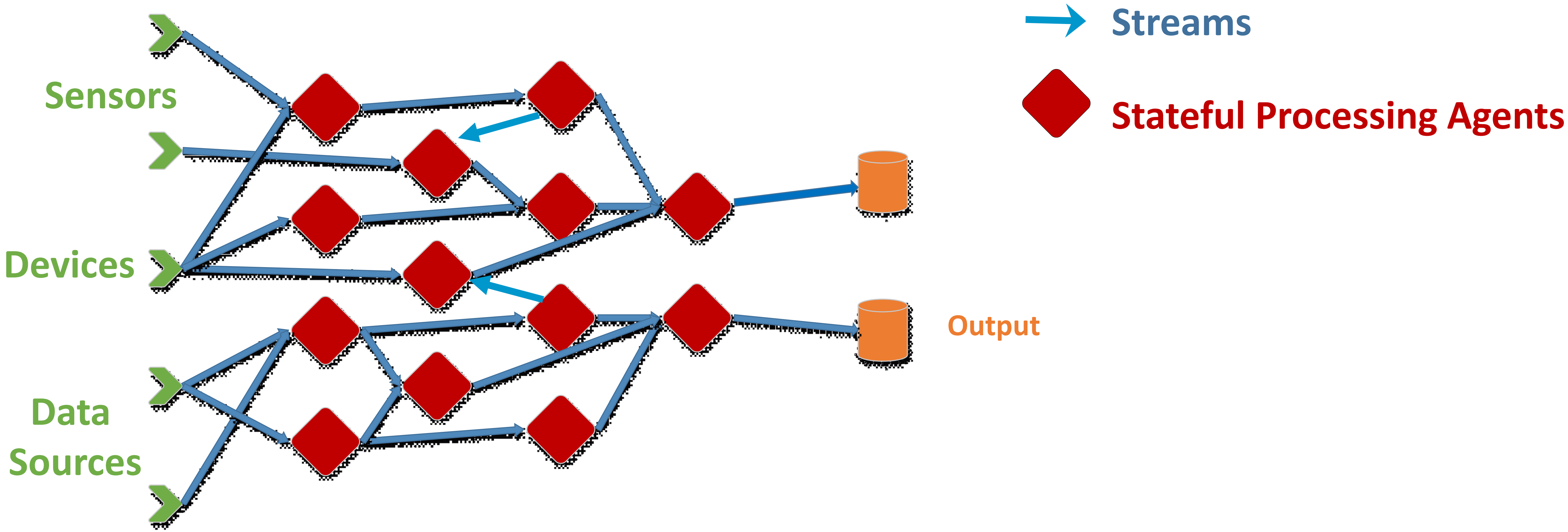
AODB Streams Requirements

- Allow fine-grained free-form compute over stream data
- Allow stream topology and processing logic to change dynamically
- Example – A stream per online user
  - Users come and go
  - Their interests change – weather location, sports, flight status, stock
  - … based on external context not on events in the stream
- Example – detect new ways of cheating in an online game
  - Re-route certain events to a cheat detector object
  - Change the logic of the cheat detector

And of course the system must be …

- Scalable
- High throughput
- Low latency
- Highly available

Conceptual System View



Actor Model Clusters Storage Writes

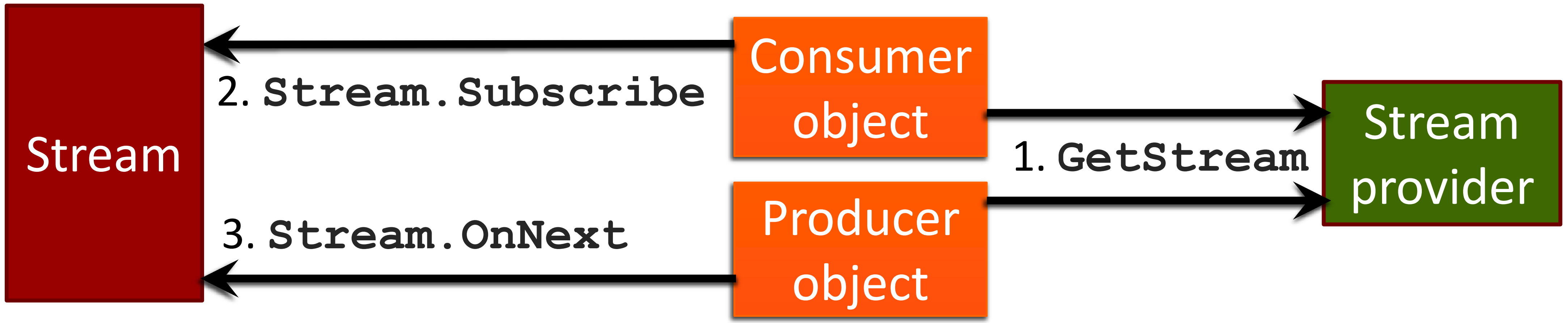
- Events relevant to an object are sent to that object
  - E.g., a player in a game, or a room in an IoT system
- The object decides when to write to storage
- Alternative model: cluster writes based on event type
  - Many event types are relevant to the same object
  - Too many writes
  - Writes to the object conflict

Orleans Streams

- A highly customizable pub-sub system
  - Defines the programming model and its implementation
  - Any Orleans object can be a stream producer or consumer
  - The queue manager is a plug-in (wrapped by a Queue Adaptor)
- A consumer can:
  - run any .NET code: C#, Trill, .NET Reactive Extensions, state machine, …
  - call other objects, e.g., for notification
- Flexible, dynamic stream topology

Programming model

1. Object calls stream provider to get a stream based on GUID+Namespace (a local call)
2. To consume from a stream, an Object subscribes to it, which returns a subscription handle
3. Producer calls **`Stream.OnNext`** to send an event to all subscribers



Stream Provider

- Can be a lightweight driver
- Can contain substantial logic
  - Split a firehose into fine-grained streams
  - Aggregate fine-grained streams into a firehose
  - Replicate events into many streams

Virtual Streams

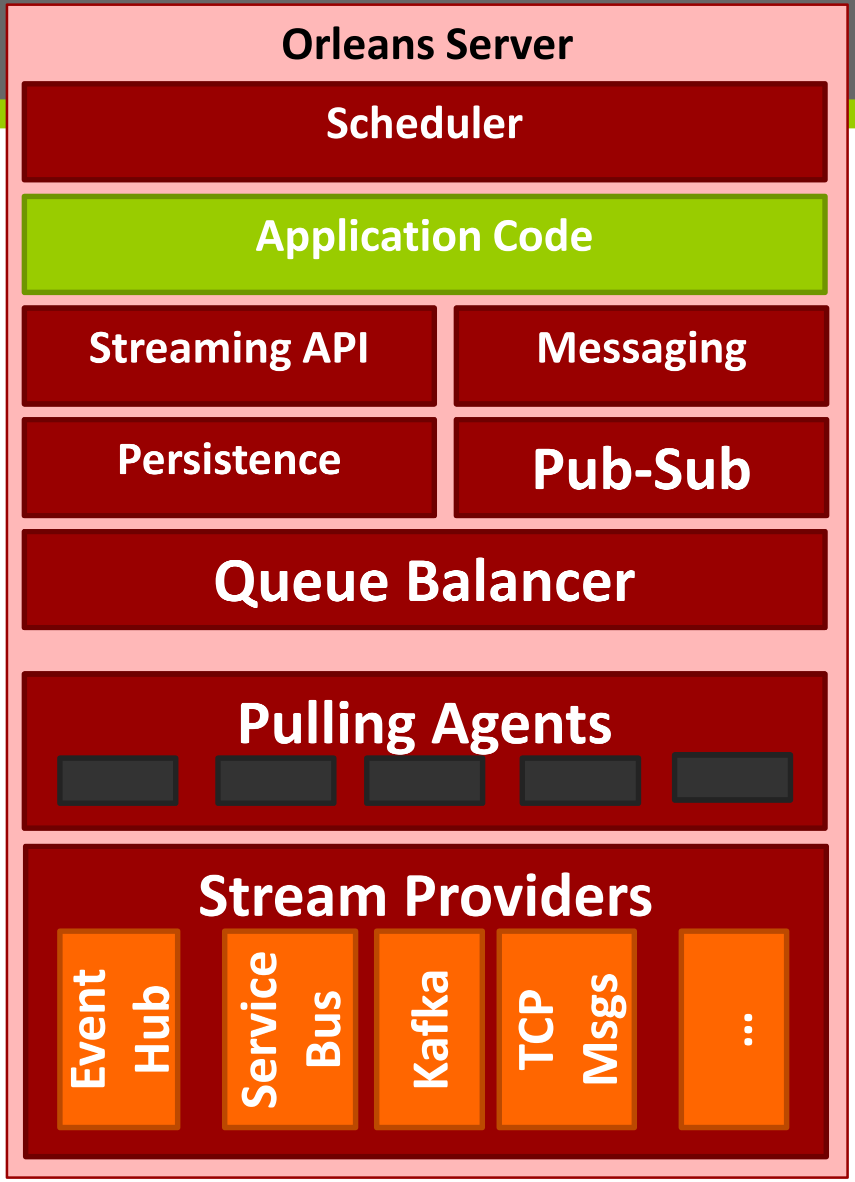
- Like a virtual actor, a stream always exists
  - It is activated on demand by sending events to it or subscribing to it
- Each subscription is durable
  - An object (subscriber) must explicitly **`Unsubscribe`**
- If an object deactivates and later is reactivated, it must invoke **`SubscriptionHandle.Resume()`** to reattach event-processing logic
  - It typically does this in its **`OnActivate`** method
  - If it didn't persist its subscription handles, then it can get them by calling **`GetAllSubscriptionHandles`**

Event Ordering

- Stream provider determines the event order between producer and consumer
- A producer can pass a **`StreamSequenceToken`** to the **`OnNext`** call
  - The **`StreamSequenceToken`** is delivered with the event so the consumer can reconstruct event order
- An object can checkpoint its state with its **`StreamSequenceToken`**
  - At recovery, the object loads its state and passes the **`StreamSequenceToken`** to **`Subscribe`** to identify the first event it should receive
  - Only some stream providers support this “rewinding”

How - Components

- Orleans server process instantiates **Pulling Agents** that get messages from the queues
- Each **Pulling Agent** loads a **Stream Provider** for the specified queuing service
  - Generic provider code is abstracted into **Queue Adaptors**
- **Queue Balancer** balances work across pulling agents and servers to prevent bottlenecks and support elasticity. It's customizable.
- **Pub-Sub** tracks all stream subscriptions, persists them, and matches stream consumers with stream producers.



Flow Control

- Agent delivers events to consumer via async RPC
  - Sends a small batch and wait for completion before sending the next batch
- A per-agent cache buffers the event stream
  - Decouples dequeuing events from delivering them to consumers
  - As the cache fills, the agent slows the dequeuing rate, thereby applying backpressure

Status

- Open source since Orleans V1, January 2015
  - http://dotnet.github.io/orleans
- Used by Halo and other Microsoft games
- Many 3rd-party users
  - Over 500 issues in Orleans GitHub mention streams
- Developed by Sergey Bykov, Jason Bragg, Alan Geller, Gabriel Kliot, Jim Larus, Ravi Pandya, Jorgen Thelin

Other Database Features

- Transactions
  - T. Eldeeb, P. Bernstein, “Transactions for Distributed Actors in the Cloud”, MSR-TR
- Indexing
  - P.A. Bernstein, M. Dashti, T. Kiefer, D. Maier: Indexing in an Actor-Oriented Database. CIDR 2017
- Geo-distribution
  - P.A. Bernstein, S. Burckhardt, et al.: Geo-distribution of actor-based services. PACMPL 1 (OOPSLA 2017)

Orleans

- http://dotnet.github.io/orleans

Microsoft