Rusta: Elastic Processing and Storage at the Edge of the Cloud

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IAD INFORMATION ACCESS DISRUPTIONS

Background

- Cloud services are becoming ubiquitous
- Blurred distinction between traditional applications and services
  - Applications are expected to synchronize automatically across devices
- Proliferation of computing devices
  - Increased demand for mobility
  - Increased opportunity for offloading

Goals (I)

- Allow cloud services to flexibly integrate computing resources available on client devices and machines
  - **Processing**: Delegate work to freely available client machines rather than paying for processing time in the cloud
  - **Storage**: Since processing touches data, they are interlinked, and decentralized storage may be desirable
- Reduce operational costs, while preserving availability and fault tolerance

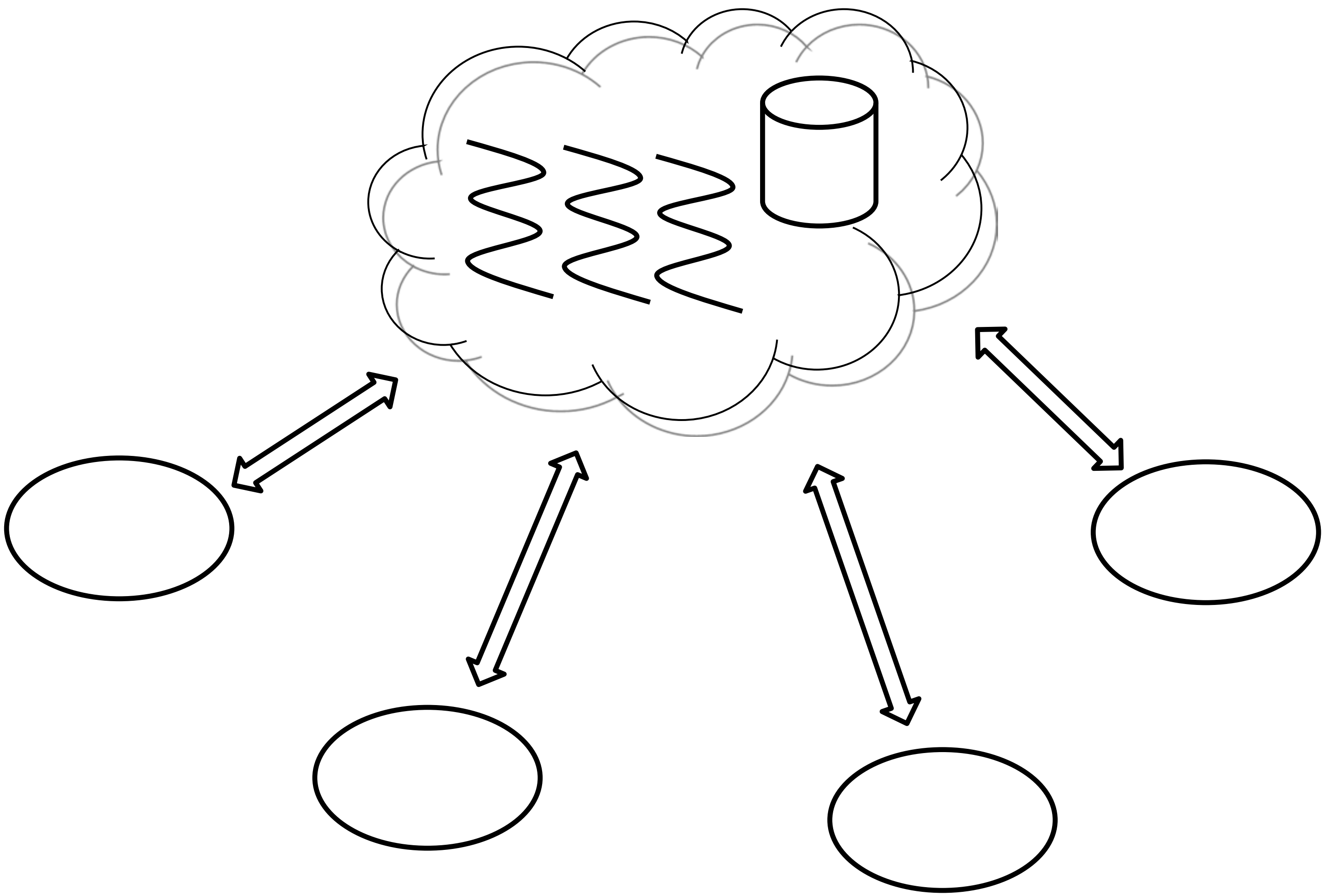
Goals (II)

- Allow traditional applications to seamlessly integrate computing resources available in the cloud
  - **Off-loading**: off-load work to the cloud to improve performance or preserve battery
  - **Synchronization**: Checkpoint and synchronize application state across multiple devices
- Decouple the mode of deployment from the application logic

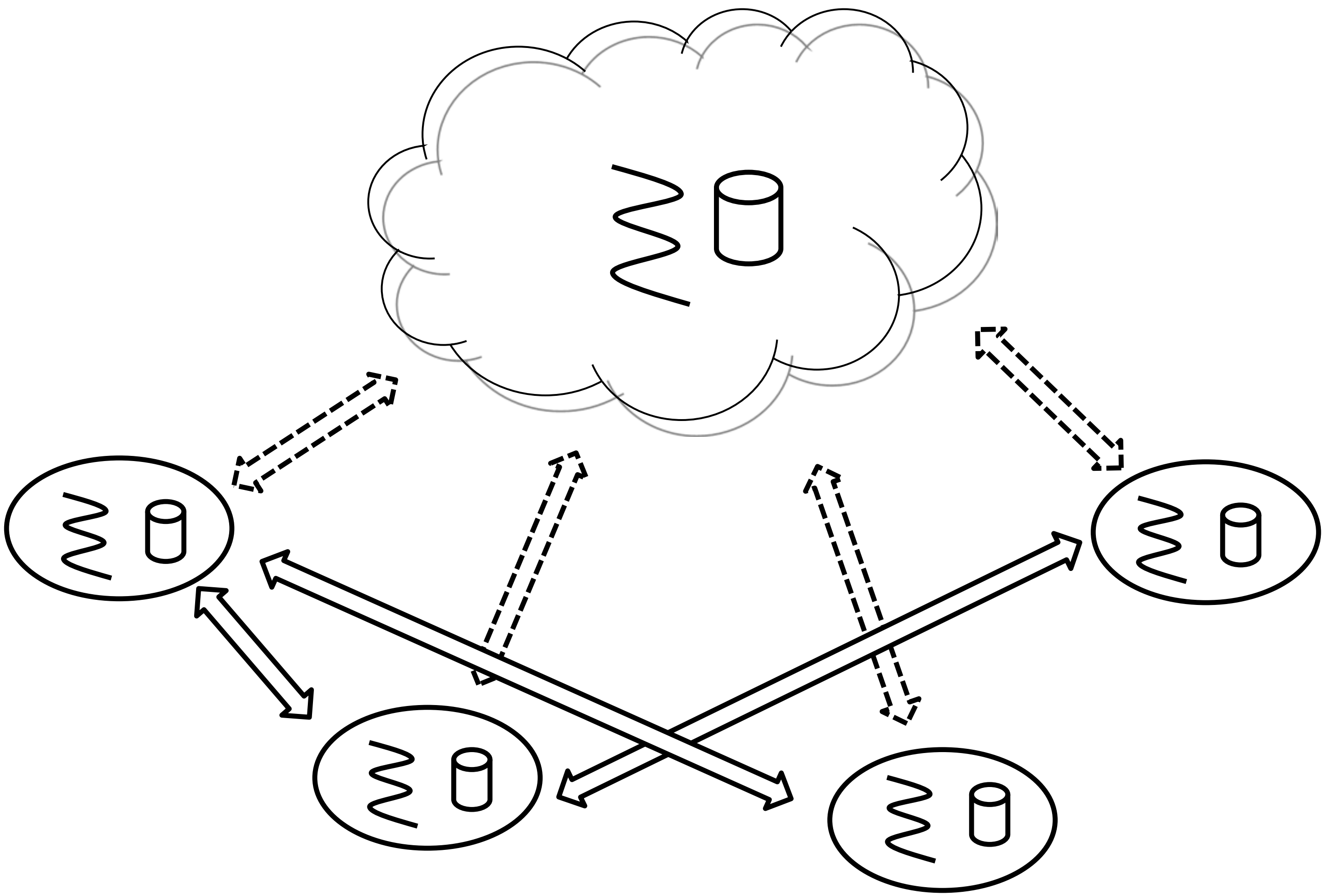
Rusta Architecture

- A centralized ***hub service*** is implemented as a conventional cloud service
  - Maintains critical system state
  - Common point of contact for all clients
  - Code repository (Java class files)
- Clients communicate sparingly with the hub
  - Bootstrapping new clients
  - Looking up other clients
  - Acquiring work to execute
  - To coordinate checkpoints

Traditional Service Architecture



Rusta Architecture



Implementation

- Hub service implemented on Google App Engine, in its Java servlet environment
  - Accessed via XMPP, i.e. using a chat client
  - “Command-line” admin interface via chat
- Client library implemented in Scala
  - Provides high-level programming abstractions for application/service developers
  - Uses Akka to drive an internal actor system
  - Communicates with the hub using GWT’s RPC
  - Polling using Google’s channel API

Scala

- High-level multi-paradigm language
  - Powerful type system
  - Flexible syntax
  - Structural pattern matching
  - **Closures**
- Runs on the Java virtual machine (JVM)
  - Integrates seamlessly with Java code
- Ideally suited for embedding domain-specific languages (DSLs)

Programming Interface

- Rusta clients are written in Scala
  - But can easily be glued to legacy Java code
- Functional continuation-based programming
  - But tailored to mimic an imperative style
- Location transparent
  - Data is accessed in a functional manner, so data locality can be arranged transparently
  - Move the computation to the data, or vice versa

Processes

- Rusta *processes* are light-weight execution units
  - Thread-like programming abstraction
  - Communicate through asynchronous message passing
  - Each process has a main message processing loop and may branch off into nested loops
- Process state is captured as a ***continuation closure***
  - Limited by heap space only; scales to hundreds of thousands of processes per machine
  - Easy to serialize and transfer process state

Hello World

- This process listens for a single system-generated *'start* message

```
object Example extends RustaApp {

  val example = new Deployment {
    group("mygroup") {
      process("myprocess") {
        case 'start => println("hello from " + me)
      }
    }
  }

  system.deploy(example)
}
```

Hello World

- This process listens for a single system-generated *'start* message

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object Example extends RustaApp {

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Closure that constitutes the main message handler

Hello World

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object Example extends RustaApp {

  val example = new Deployment {
    group("mygroup") {
      process("myprocess") {
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Structural pattern matching

Hello World

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Function of the Rusta API, taking curried arguments

Hello World

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object Example extends RustaApp {

  val example = new Deployment {
    group("mygroup") {
      process("myprocess") {
        case 'start => println("hello from " + me)
      }
    }
  }

  system.deploy(example)
}
```

Process name and other optional arguments

Group Namespace

- Rusta *groups* define a hierarchical namespace for processes and data items
- Groups delineate sets of mutually trusted clients
  - Processes may migrate freely within their group
  - Data may be replicated freely within its group
- Allows fine-tuning trade-offs between privacy, availability, and elasticity
  - E.g., larger groups give more elasticity
- Potentially initialized from a social network

Message Passing

- Messages are arbitrary (immutable) objects
- Receivers use structural pattern matching to select (and parse) messages to process
- Senders may specify a reply handler
  - Specifies how to (eventually) process a reply
  - Messages are tagged with sequence numbers that are associated with pending reply handlers
  - Invoked asynchronously whenever a reply arrives
  - Syntactically tied to the sending code, improving legibility

Message Passing Example

```
group("images") {
  process("main") {
    case 'start => {
      send("thumbnails", ('get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }
}
```

Message Passing Example

```
group("images") {
  process("main") {
    case ’start => {
      send("thumbnails", (’get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }
}
```

Destination process

Message Passing Example

```
group("images") {
  process("main") {
    case 'start => {
      send("thumbnails", ('get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }
}
```

Message = arbitrary object
(a tuple in this case)

Message Passing Example

```
group("images") {
  process("main") {
    case ’start => {
      send("thumbnails", (’get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }
}
```

Reply handler

Data Access

- Conceptually similar to sending messages and handling replies
  - Lookups specify a data key to look up, and a closure to execute on the associated data value
- Just like the closures that capture process state, these closures can be serialized and transferred
  - Potentially sending the computation to the data
  - Maintains location transparency while encouraging data locality

```
group("images") {
  process("main") {
    case 'start => {
      send("thumbnails", ('get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }

  process("thumbnails") {
    case ('get, path: String) => {
      getData(path) {
        case (image: Image, thumbnail) => {
          reply(thumbnail)
        }
        case (image: Image, null) => {
          val tn = makeThumbnail(image)
          putData(path, (image, tn))
          reply(tn)
        }
        case null => reply(null)
      }
    }
  }
}
```

Look up a data item and process it asynchronously

```
group("images") {
  process("main") {
    case 'start => {
      send("thumbnails", ('get, "image.jpg")) {
        case null => println("No such image")
        case tn: Image => showImage(tn)
      }
    }
  }

  process("thumbnails") {
    case ('get, path: String) => {
      getData(path) {
        case (image: Image, thumbnail) => {
          reply(thumbnail)
        }
        case (image: Image, null) => {
          val tn = makeThumbnail(image)
          putData(path, (image, tn))
          reply(tn)
        }
        case null => reply(null)
      }
    }
  }
}
```

The context is preserved, so that the original message can still be replied to

Stateful Processes

- Close over variables in outer scopes
- The Scala compiler includes the variables in the closure's state
- Used for internal state, private to a process
  - E.g., for data aggregation

```
group("mygroup") {
  var x = 0

  process("myprocess") {
    case ‘getx => println("x = " + x); x += 1
  }
}
```

Ongoing Work

- Scheduling algorithms in the hub
  - Distribute processes among eligible clients
  - Process migration
- Data placement policies
  - Replication costs vs. availability
  - Cloud storage as a fallback to guarantee availability
- Checkpointing algorithms
  - Consistent cuts

Applications

- File sharing
  – Basic image sharing application
- Collaboration systems
- Multi-cloud services
- Lifelog image analysis
- Personal sensor data processing (soccer domain)
- Social networking
  – Analytics driven by client machines to empower users while preserving privacy

Summary

- Rusta allows flexible and decentralized deployment of cloud services
  - Alternatively: easy offloading from clients to the cloud, and to other clients
- Simple centralized architecture
  - But the central hub is not a bottleneck
- High-level programming interface in Scala
  - Light-weight and location-transparent processes
  - Easy to migrate (compared to e.g., thread migration)
- Process checkpointing and migration currently implemented
  - Basic image sharing application developed

Questions?