Programming Distributed Systems

Programming Models for Distributed Systems

Annette Bieniusa

FB Informatik
TU Kaiserslautern

What is a Programming Model? [3]

- A programming model is some form of abstract machine
  - Provides operations to the level above
  - Requires implementations for these operations on the level(s) below
- Simplification through abstraction
- Standard interface that remains stable even if underlying architecture changes
- Provide different levels of abstraction
- Often starting point for language development

⇒ Separation of concern between software developers and framework implementors (runtime system, compiler, etc.)

Properties of good programming models

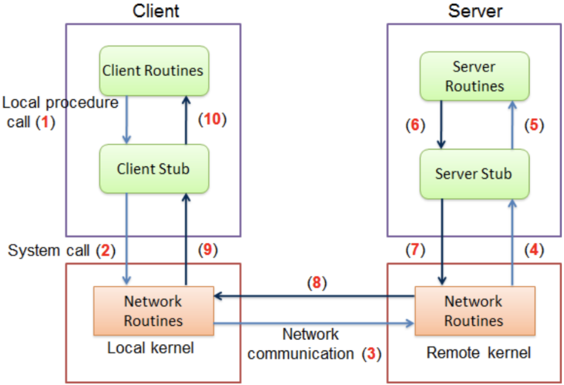
- Meaningful abstractions
- System-architecture independent
- Efficiently implementable
- Easy to understand

What kind of abstractions should a programming model for distributed systems provide?

Remote Procedure Call

Remote Procedure Call (RPC) [2]

- Rather broad classifying term with changing meaning over time
    - From client-server design to interconnected services
- *Two entities (caller/callee) with different address spaces communicate over some channel in a request-response mechanism*
- Examples: CORBA (Common Object Request Broker Architecture), Java RMI (Remote Method Invocation), SOAP (Simple Object Access Protocol), gRPC (Protocol Buffers), Twitter Finagle . . .

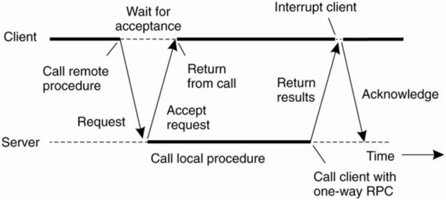

Client
Server
Client Routines
Local procedure call (1)
(10)
Client Stub
System call (2)
(9)
Network Routines
Local kernel
Server Routines
(6)
(5)
Server Stub
(7)
(4)
(8)
Network Routines
Network communication (3)
Remote kernel

Flaws of RPC

- Location transparency (i.e. request to remote service looks like local function call) masks the potential of distribution-related failures
- RPCs might timeout, requires usually special handling such as retrying
- Local functions do not need to deal with the problem of idempotence
- Execution time is unpredictable
- Passing of objects is complex (e.g. might need to serialize referenced objects)
- Translating data types between languages might rely on semantical approximation

Aspects of modern RPC

- Language-agnostic
- Serialization (aka marshalling or pickling)
    - JSON, XML, Protocol Buffers, ...
- Load-balancing
    - SOA (Service-oriented architecture) ⇒ Microservice architectures!
- Asynchronous



⇒ RPC as term gets more and more diffuse

Futures and Promises

- "Asynchronous RPC"
- A future is a value that will eventually become available
- Two states:
  - *completed*: value is available
  - *incomplete*: computation for value is not yet complete
- Strategies: Eager vs. lazy evaluation
- Typical application: Web development and user interfaces

Example

```
interface ArchiveSearcher { String search(String target); }

class App {
   ExecutorService executor = ...
   ArchiveSearcher searcher = ...
   void showSearch(final String target)
       throws InterruptedException {
     Future<String> future
       = executor.submit(new Callable<String>() {
         public String call() {
             return searcher.search(target);
         }});
     displayOtherThings(); // do other things while searching
     try {
       displayText(future.get()); // use future
     } catch (ExecutionException ex) { cleanup(); return; }
   }
}
```

From Oracle's Java Documentation

Actors and Message Passing

Characteristics of Actor Model [**Hewitt**]

- Actors are isolated units of computation + state that can send messages asynchronously to each other
- Messages are queued in mailbox and processed sequentially when they match against some pattern/rule
- No assumptions on message delivery guarantees
- (Potential) State + behavior changes upon message processing[1]
- Very close to Alan Kay's definition of Object-Oriented Programming

Actors in the Wild

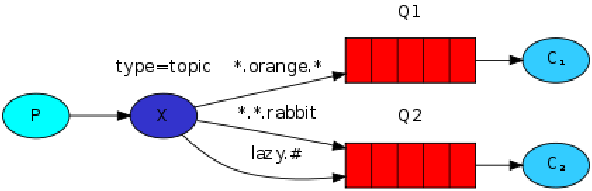
- Erlang
  - Process-based
  - Pure message passing
  - `monitor` and `link` for notification of process failure/shutdown
  - OTP (Open Telecom Platform) for generic reusable patterns
- Akka
  - Actor model for the JVM
  - Purges non-matching messages
  - Enforces parental supervision
  - Included in Scala standard library
- Orleans
  - Actors for Cloud computing
  - Scalability by replication
  - Fine-grain reconciliation of state with transactions

Message brokers

- Message-oriented middleware which stores messages temporarily and forwards them to registered recipients
- Patterns: Publish-subscribe, point-to-point
- Acts as buffer for unavailable and overloaded recipients
- Decoupling of sender and receiver(s)
- Efficient 1-to-n multicast
- Advanced Message Queuing Protocol (AMQP) standardizes queuing, routing, reliability and security
- Delivery guarantees (at-most-once, at-least-once, exactly-once)

Example: RabbitMQ

- Supports (amongst others) publish-subscribe pattern
- Typical usage: Topics as routing keys



- Q1 is interested in all the orange animals
- Q2 wants to hear everything about rabbits, and everything about lazy animals
- Messages that don't map any binding get lost
- Messages are maintained in the queue in publication order

Stream processing

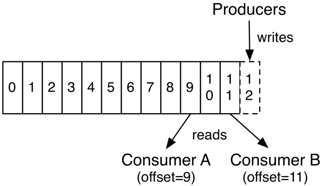
- (Infinite) Sequence of data that is incrementally made available
- Example: Sensor data, audio / video delivery, filesystem APIs, etc.
- Producers vs. Consumers
- Notions of window and time: Consumers will receive only messages after subscribing
- Here: Event stream where data item is atypically associated with timestamp

Classification of stream processing systems

1. What happens if producer sends messages faster than the consumer can handle?
    - Drop messages
    - Buffer messages
    - Apply backpressure (i.e. prevent producer from sending more)
2. What happens if nodes become unreachable?
    - Loose messages
    - Use replication and persistence to preserve non-acknowledged messages

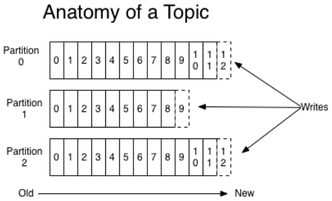
Log-based message brokers

- Example: Kafka [https://kafka.apache.org]
- Message buffers are typically transient: Once the message is delivered, the message is deleted
- Idea: Combine durable storage with low-latency notification!



Scalability and fault-tolerance for replicated logs

- For scalability, partitioning of log on different machines
- For fault-tolerance, replication on different machines



- Need to ensure same ordering on all replicas (⇒ Total-order broadcast)
- Can easily add consumers for debugging, testing, etc.
- *Ideas*: Event-sourcing, immutability and audits

Batch-processing

- Static data sets that has known/finite size
- Need to artificially batch data into by day, month, minute, . . .
- Typically large latencies

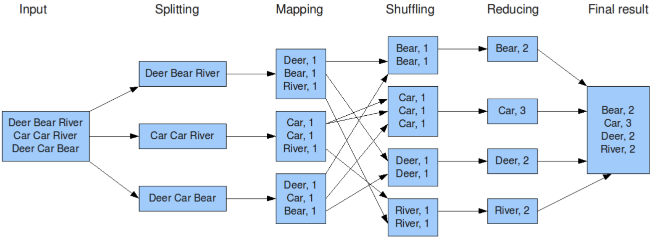
The Future: Distributed Programming Languages

From Model to Language

- Challenges: Partial failure, concurrency and consistency, latency, . . .

1. Distributed Shared Memory
   - Runtime maps virtual addresses to physical ones
   - “Single-system” illusion
2. Actors
   - Explicit communication
   - Location of processes is transparent
3. Dataflow
   - Data transformations expressed as DAG
   - Processes are transparent
   - Example: MapReduce (Google), Dryad (Microsoft), Spark

Example: WordCount in MapReduce



Further reading

- Material collection by Northeastern University, CS7680 Special Topics in Computing Systems: Programming Models for Distributed Computing

Further reading I

[1] Gul Agha. „Concurrent Object-Oriented Programming“. In: *Commun. ACM* 33.9 (1990), S. 125–141. DOI: 10.1145/83880.84528. URL: http://doi.acm.org/10.1145/83880.84528.

[2] Andrew Birrell und Bruce Jay Nelson. „Implementing Remote Procedure Calls“. In: *ACM Trans. Comput. Syst.* 2.1 (1984), S. 39–59. URL: https://doi.org/10.1145/2080.357392.

[3] David B. Skillicorn und Domenico Talia. „Models and Languages for Parallel Computation“. In: *ACM Comput. Surv.* 30.2 (1998), S. 123–169. DOI: 10.1145/280277.280278. URL: http://doi.acm.org/10.1145/280277.280278.