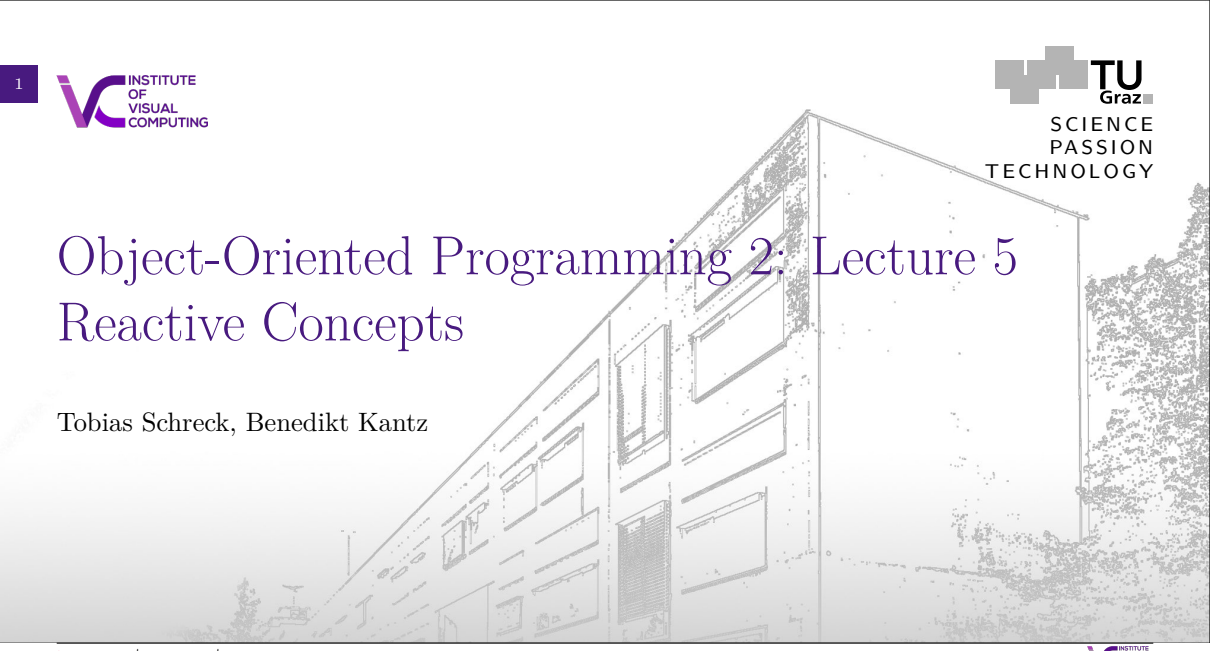
INSTITUTE OF VISUAL COMPUTING

TU Graz
SCIENCE
PASSION
TECHNOLOGY

Object-Oriented Programming 2: Lecture 5 Reactive Concepts

Tobias Schreck, Benedikt Kantz



Have you used `async/await`?

Overview

- Reactive Programming: Concepts
- Indirect Communication: Groups, Message Queues
- Stream Processing
- Virtual Threads
- Futures/Asynchronous Programming

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Reactive Manifesto I

Development of reactive software

- Need for reactive programming nowadays:
  - Big data
  - Heterogeneous environments from small devices to server farms
  - User expectations: fast responses in milliseconds, always available

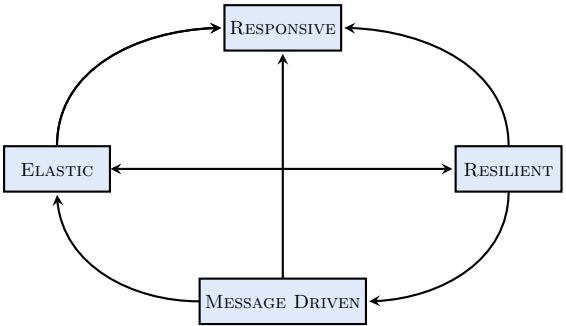
Reactive Manifesto II

Development of reactive software

- Processing done in parallel
- Stream-orientation
- Asynchronous processing
- Respond to data (and events, failures, messages)
- rather than loading all data and processing it completely before coming back with a result
- Coupling of heterogeneous applications/components
- Goals summarized in the **Reactive Manifesto**

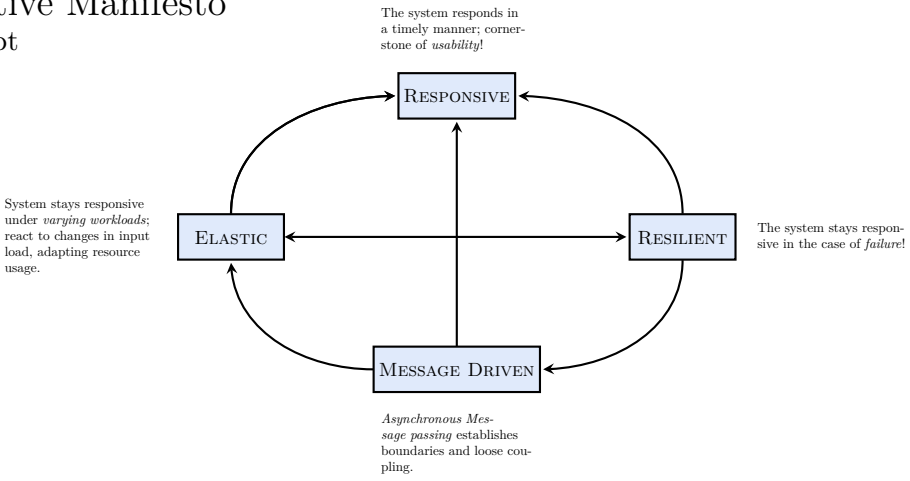
Reactive Manifesto

Concept



Based on the *Reactive Manifesto* [1]

Reactive Manifesto
Concept



Based on the *Reactive Manifesto* [1]

Indirect Communication: Why?

- Basis for distributed systems, interoperability, parallel and reactive applications, redundancy ...
- Temporal Uncoupling
  - Asynchronous communication
  - Sender and receiver do not need to be active (or even exist) at the same time
  - Thread-based tasks!
- Space Uncoupling
  - Identity of sender or receiver does not need to be known to other side
  - Allow exchange, update, or addition of recipients

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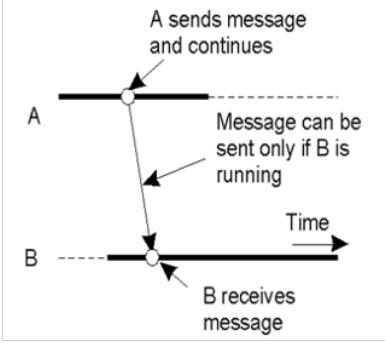
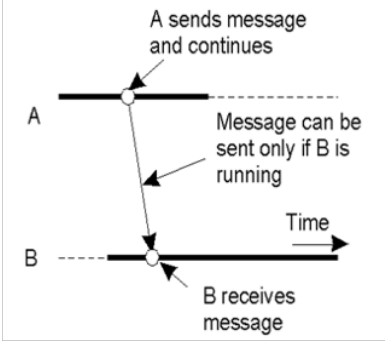
Transient Communication



Transient asynchronous
only if receiver is running

Transient Communication



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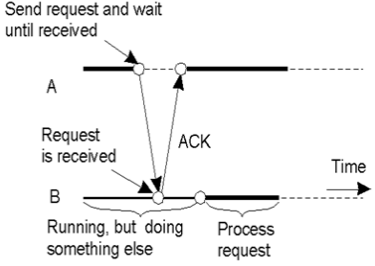
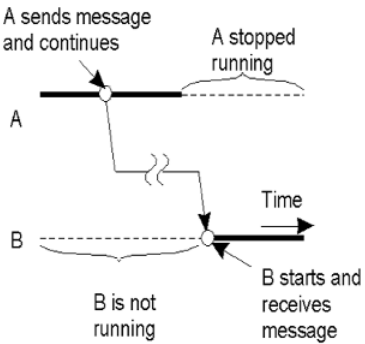


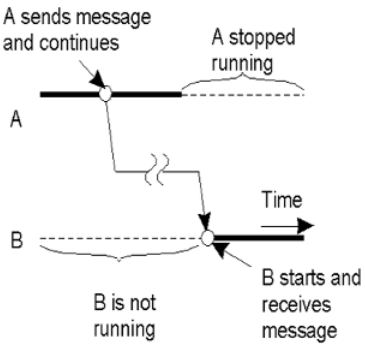
Receiver-oriented transient synchronous
Store on receiver side, sender blocks until acknowledgment of receipt, issued immediately

Persistent Communication



Persistent asynchronous
store on sender side

Persistent Communication



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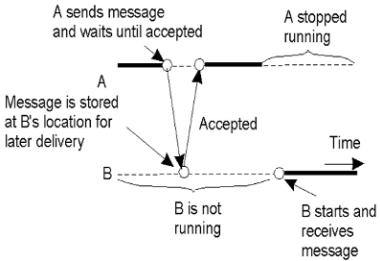

Persistent synchronous
store on receiver side

Push vs. Pull

- Pull Notification
  - Information sent only after request (Polling)
- Push Notifications
  - Distributed systems often need updates on local object changes (events)
  - Useful to connect heterogeneous systems
  - Efficient notification via multicast
  - Registering of callbacks (reactive programming)
- Reliable or unreliable notification possible

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Applications

- Indirect communication used for distributed systems in which ...
  - Changes are happening frequently
    - Nodes connect and disconnect frequently
  - Nodes are unknown (anonymous nodes)
- Examples
  - Mobile environments
  - Peer-to-peer communication

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Motivation

- Why indirect communication?
  - "All problems in computer science can be solved by another level of indirection." (David Wheeler, father of the subroutine)
- But: indirect communication can be expensive!
  - "There is no performance problem that cannot be solved by eliminating a level of indirection." (Jim Gray, Pioneer of Database Research, Turing Award Winner 1998)

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Space and Time Coupling in Distributed Systems

Properties

	Time-Coupled	Time-Uncoupled
Space-Coupling	Communication directed towards a given receiver or receivers; receiver(s) must exist at that moment in time	Communication directed towards a given receiver or receivers; sender(s) and receiver(s) can have independent lifetimes
Space-Uncoupling	Sender does not need toknow the identity of the receiver(s); receiver(s) must exist at that moment in time	Sender does not need to know the identity of the receiver(s); sender(s) and receiver(s) can have independent lifetimes

Based on Ananda and Poo [2].

Space and Time Coupling in Distributed Systems

Examples

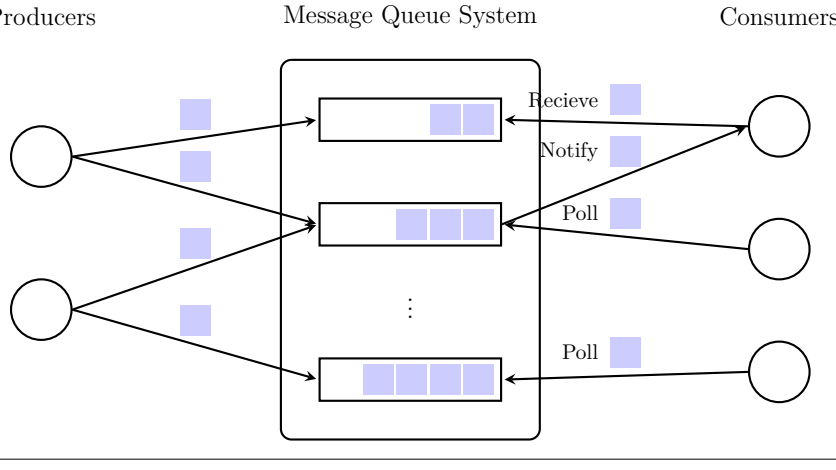
	Time-Coupled	Time-Uncoupled
Space-Coupling	Message passing, remote invocation	Mail
Space-Uncoupling	IP Multicast	Message Queues

Based on Ananda and Poo [2].

Group Communication

- Example (network): IP multicast
  - Infrastructure support to deliver IP packets to multiple destinations
- Example (application): Mailing list
  - List server expands to list names
- Commonalities
  - Clients: need operations to join, leave groups
  - Multicast vs broadcast

Message Queues
Overview



Message Queues
Examples: DIY

- Message Passing
  - Implement queues on sender and recipient side
  - Marshalling
- Message Queues
  - Queues decoupled from sender and receiver
  - First In First Out (FIFO) or priority

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Message Queues
Examples: Middlewares

- RabbitMQ [1]
- MQTT: IoT Applications [2]
- Apache Kafka [3]
  - Widely used by many big companies
  - Netflix, Oracle, ...
- All of them: APIs for all major languages

[1] https://www.rabbitmq.com/tutorials
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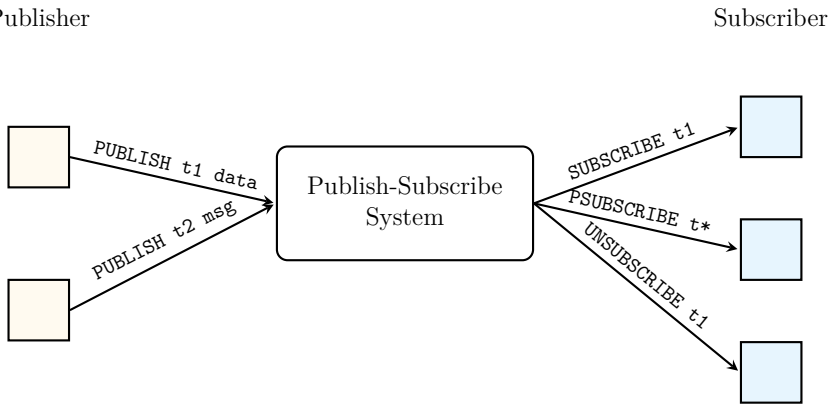
Publish-Subscribe

Overview



Publish-Subscribe based on on Ananda and Poo [2] and Redis [3].

Publish-Subscribe
Definition

Publish-Subscribe

- Participants do not know each other (Spatial uncoupling)
- Broker manages participants, distributed brokers (i.e. Redis)
- Delivery type: Direct (multicast), MQ (temporal uncoupling)

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Delivery Guarantees

- **At most once**: not resilient, usually ephemeral messages (*Redis*)
- **At least once**: resilient, but might double deliver messages
- **Exactly once**: guarantees exactly one delivery of each message (*Kafka*)

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Publish-Subscribe
Subscription modes

- By Channel: e.g. name
- By Topic: flag on channel
- By Type: super-topic
- By Content: Based on structure of content/attributes

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Publish-Subscribe I

Example: Redis[a]

[a] https://redis.io/docs/latest/develop/pubsub/

```
SUBSCRIBE alerts.user
```

- Subscribe client to channel
- Delivery type: *At-most-once* (Compare Kafka: *Exactly Once*)
- Selection: by channel

Publish-Subscribe II

Example: Redis[a]

[a] https://redis.io/docs/latest/develop/pubsub/

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Publish-Subscribe III

Example: Redis[a]

[a] https://redis.io/docs/latest/develop/pubsub/

```
PUBLISH alert.user singout
```

- Publish the data in channel
- Data can be arbitrary string (e.g. Base64/JSON encoded data!)

Stream Processing

- Streams provide a high-level abstraction for processing sequences of elements
- Can be processed sequentially or in parallel
- Functional-style operations (map, filter, reduce, etc.)

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Streams
Examples

- See a detailed example in the repository!

Executors for Virtual Threads (Java 21+)

- Java 21 introduces virtual threads for lightweight concurrency
- Virtual creates an executor that assigns each task to a new virtual thread
- Great for high-concurrency workloads: blocking I/O threads!

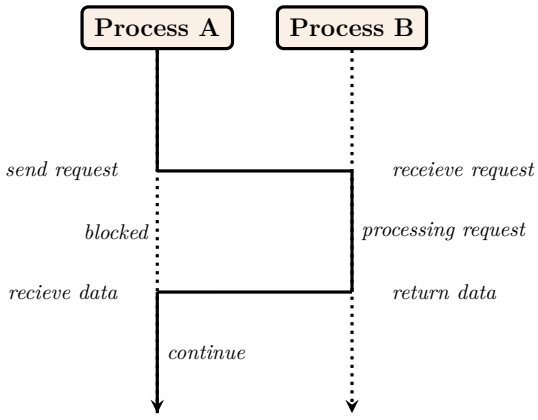
```
try (ExecutorService vexec =
    Executors
        .newVirtualThreadPerTaskExecutor()) {
        vexec.submit(() -> doWork());
}
```

Virtual Threads
Examples

- See a detailed example in the repository!

Asynchronous Programming

- Until now: blocking access to I/O (network, files, ...)
- Enables the process to continue running while waiting on blocked tasks



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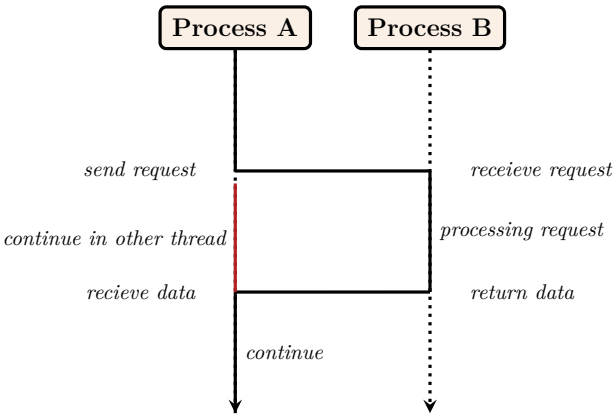

Asynchronous Examples
Java Futures

- Java uses `Future` and `CompletableFuture` for async tasks.
- Submit tasks to an executor and retrieve results later.

```
ExecutorService executor =
↪  Executors.newSingleThreadExecutor();
Future<Integer> future = executor.submit(() -> {
    Thread.sleep(1000);
    return 42;
});
System.out.println("Doing other work...");
Integer result = future.get(); // blocks if not done
System.out.println("Result: " + result);
executor.shutdown();
```

Asynchronous Examples
JavaScript `async/await`

- JavaScript uses `async` functions and `await` for promises.
- Allows writing asynchronous code that looks synchronous.

```
async function fetchData() {
    let response = await
    ↪  fetch('https://api.example.com/data');
    let data = await response.json();
    console.log(data);
}
console.log("Fetching...");
fetchData();
```

Asynchronous Examples
Python `async/await`

- Python uses `async def` and `await` for coroutines.
- Requires an event loop to run async functions.

```python
import asyncio
async def main():
    print("Waiting...")
    await asyncio.sleep(1)
    print("Done!")
asyncio.run(main())
```

Feedback

Bibliography I

References

[1] J. Boner, D. Farley, R. Kuhn, and M. Thompson, Sep. 2014. [Online]. Available: https://www.reactivemanifesto.org/pdf/the-reactive-manifesto-2.0.pdf#page=2.00.

[2] A. Ananda and G. Poo, **Distributed systems: Concepts and design: By george coulouris, jean dollimore and tim kindberg, addison-wesley, 2nd ed, 1994, 644 pp, isbn 0201624338,** eng, *Computer communications*, vol. 18, no. 7, pp. 521–522, 1995, ISSN: 0140-3664.

[3] **Redis Pub/sub,** [Online; accessed 5. Oct. 2025], Oct. 2025. [Online]. Available: https://redis.io/docs/latest/develop/pubsub.