Solving the Overproduction Problem in Reactive Programming using Feedback Control

Master Thesis Defense

Richard van Heest

Interactive vs. Reactive

Interactive program

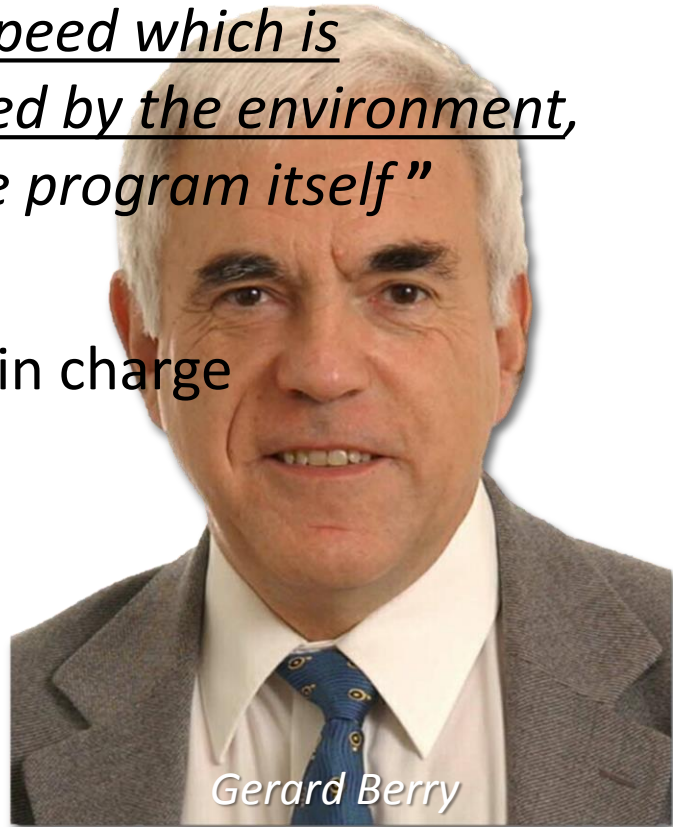
"interacts at its own speed with users or with other programs"

consumer in charge

Reactive program

"maintains a continuous interaction with its environment, but at a speed which is determined by the environment, not by the program itself"

producer in charge



Interactive vs. Reactive

Interactive program

```
val it = Iterable(0, 1, 2, 3)

val iterator = it.iterator
while (iterator.hasNext)
    println(iterator.next())

for (i <- it)
    println(i)

it.foreach(println)
```

Reactive program

```
val obs = Observable(0, 1, 2, 3)

obs.subscribe(println(_))
```

Interactive vs. Reactive

Interactive program

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val it = Iterable(0, 1, 2, 3)

val iterator = it.iterator
while (iterator.hasNext)
    println(iterator.next())

for (i <- it)
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it.foreach(println)

it.map(i => i + 1)
  .filter(i => i % 2 == 0)
  .foreach(println)
```

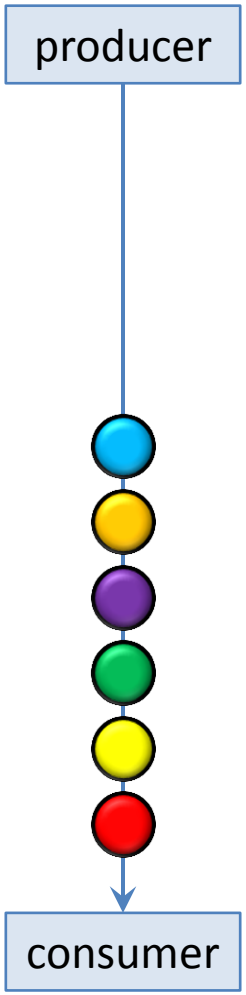
Reactive program

```
val obs = Observable(0, 1, 2, 3)

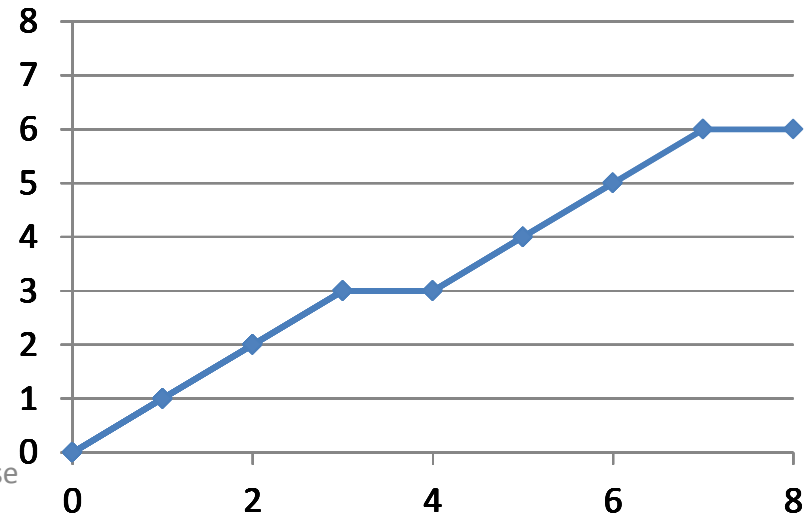
obs.subscribe(println(_))

obs.map(i => i + 1)
   .filter(i => i % 2 == 0)
   .subscribe(println(_))
```

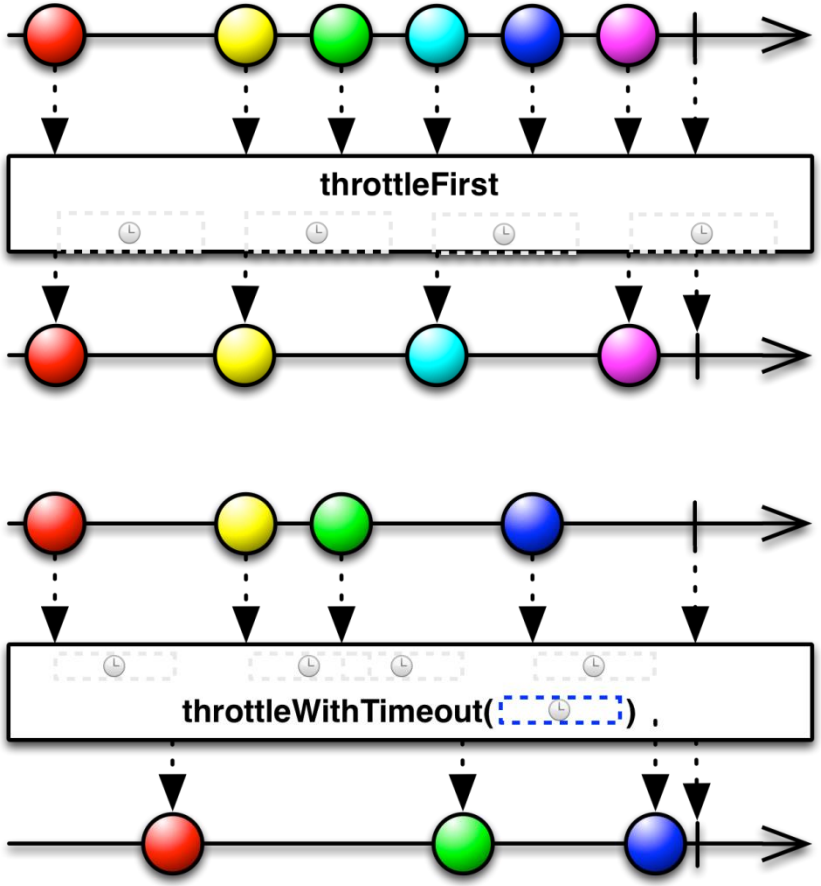
Fast producer, slow consumer

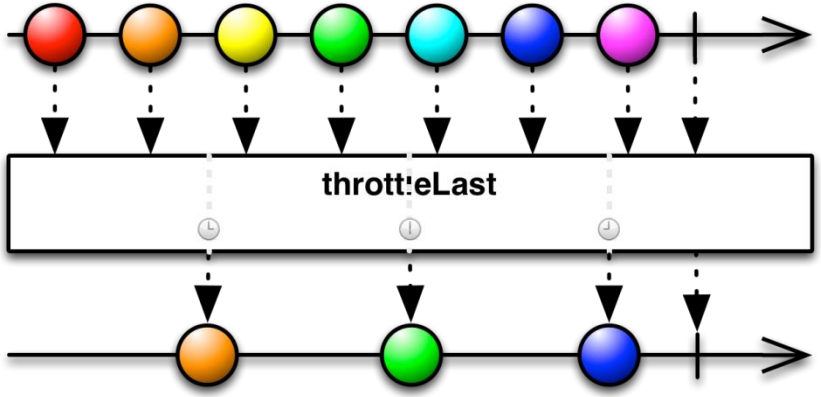


time = 8

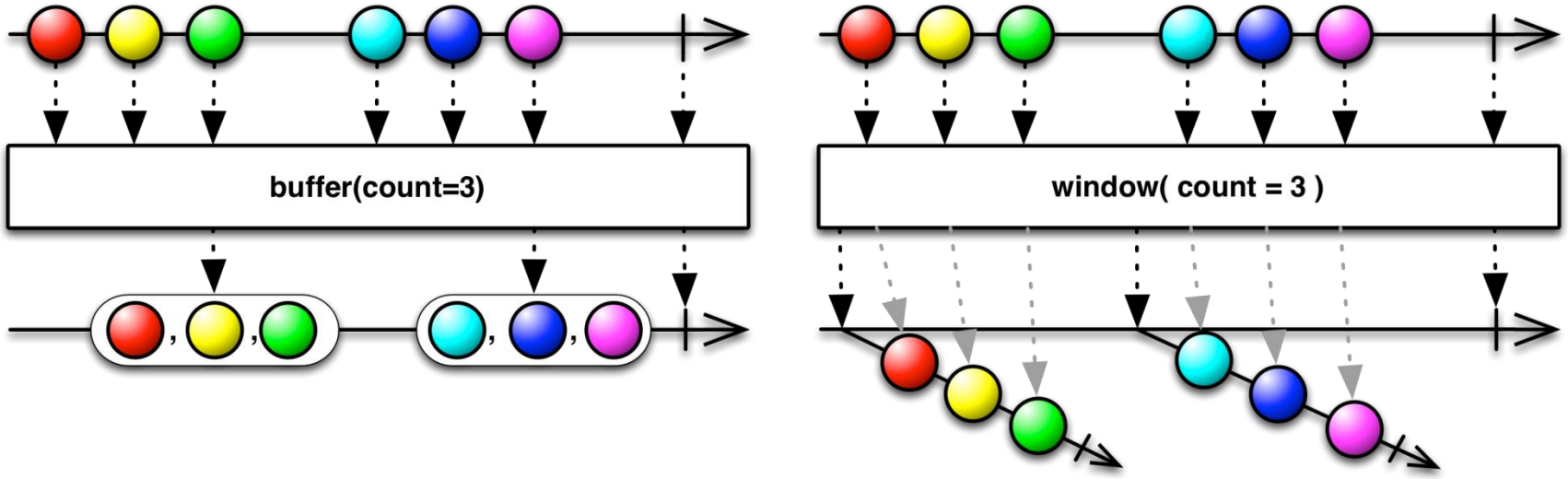


Lossy operators

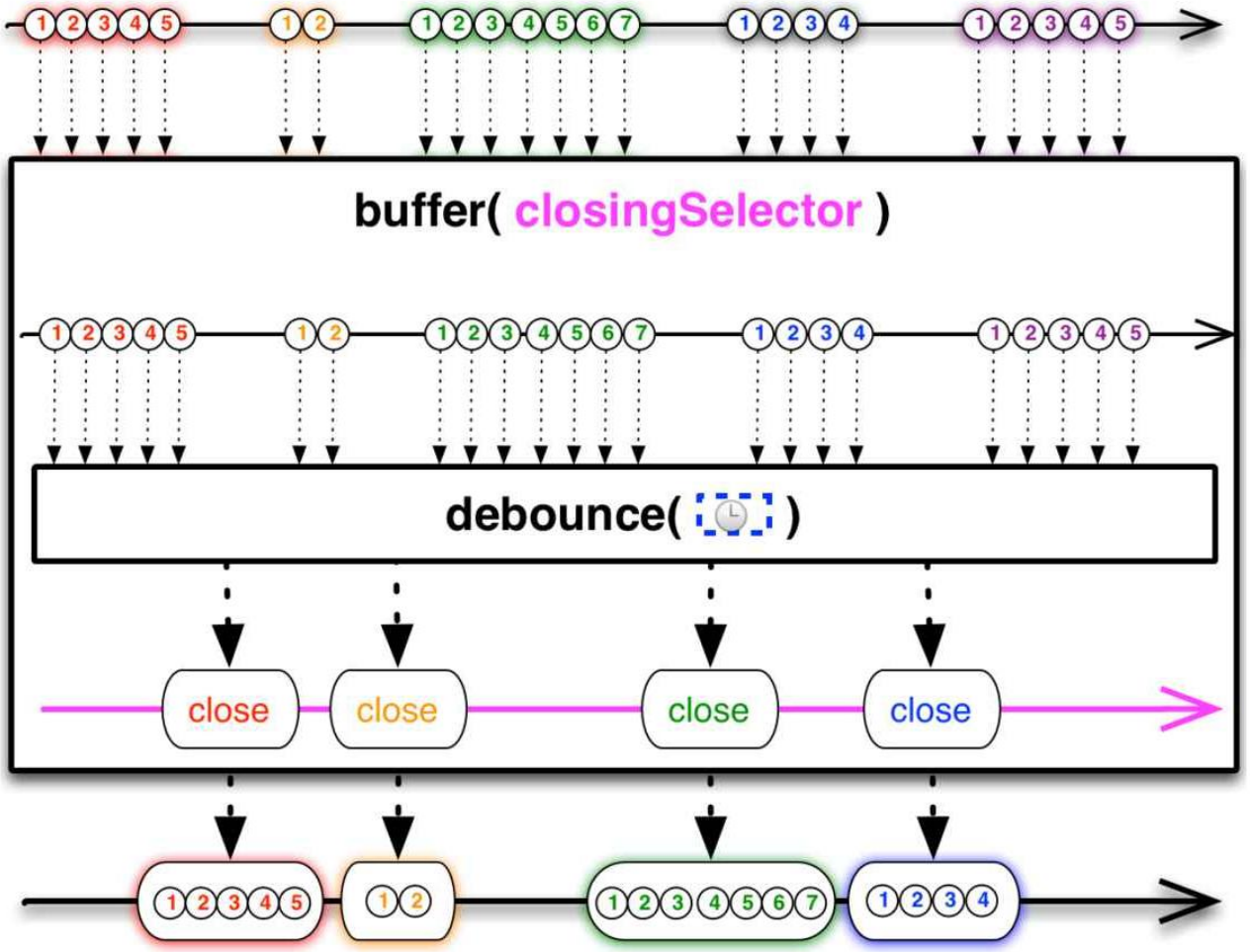




Loss-less operators



Combined lossy & lossless operators



The source matters!

Cold source

- Can be interacted with
- Multiple subscribers: stream duplicates
- Examples:
  - Database query result
  - Network response
  - In-memory list of data

Hot source

- Can’t be interacted with
- Multiple subscribers: stream continues (broadcast)
- Examples:
  - Mouse events
  - Stock tickers
  - Clocks

The source matters!

Cold async source

- Can be interacted with
- Dependent on a notion of time

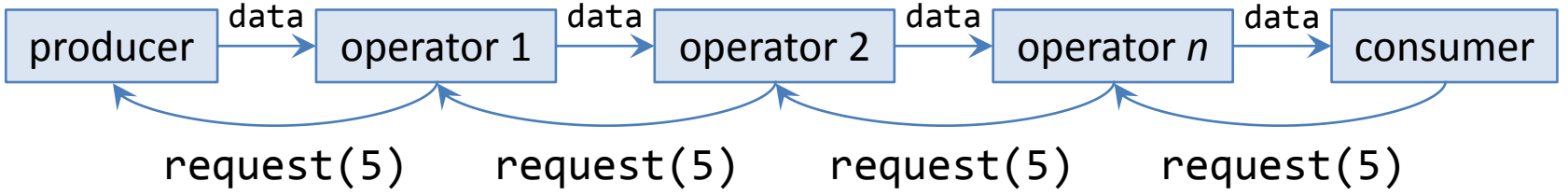
- Examples:
  - Database query result
  - Network response

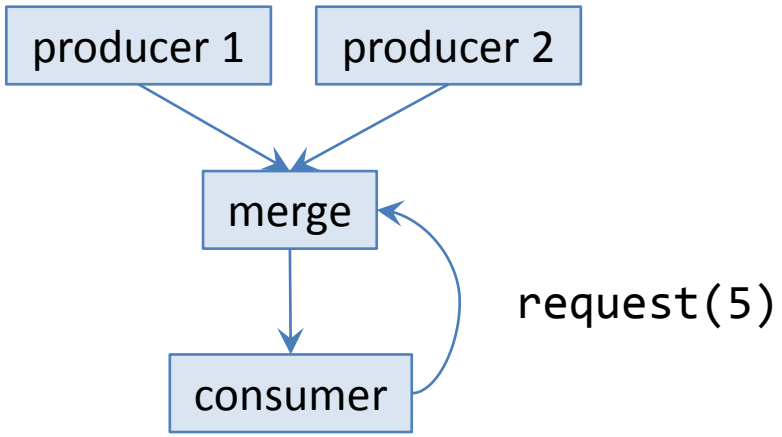
Cold sync source

- Can be interacted with
- Not dependent on a notion of time

- Examples:
  - In-memory list of data
  - `Observable(0, 1, 2, 3)`

Backpressure/Reactive Streams






```
producer1.merge(producer2)
  .subscribe(println(_))
```

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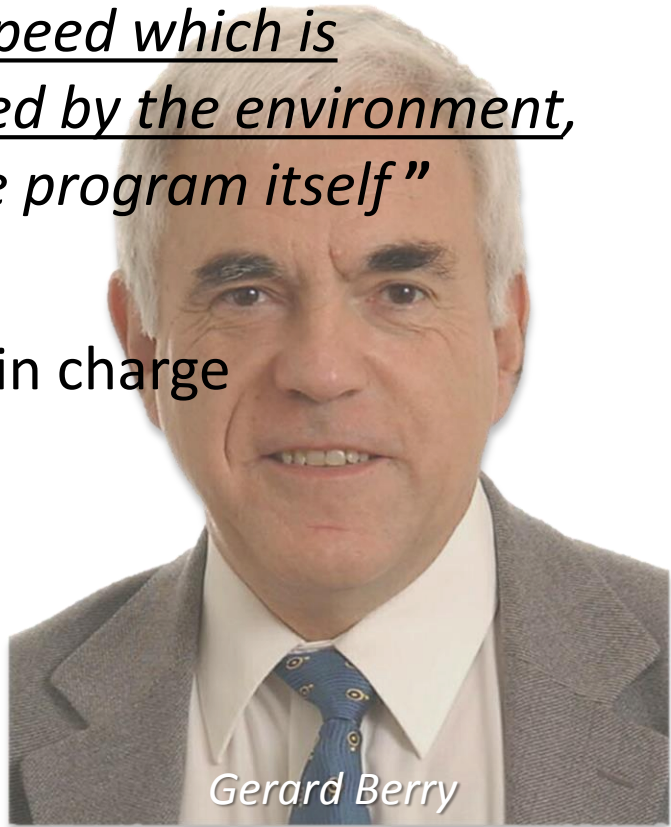


Let’s backtrack

Cold source

- Can be interacted with
- Maybe dependent on time
- Backpressure
  - Not reactive
  - Affects operators

Hot source

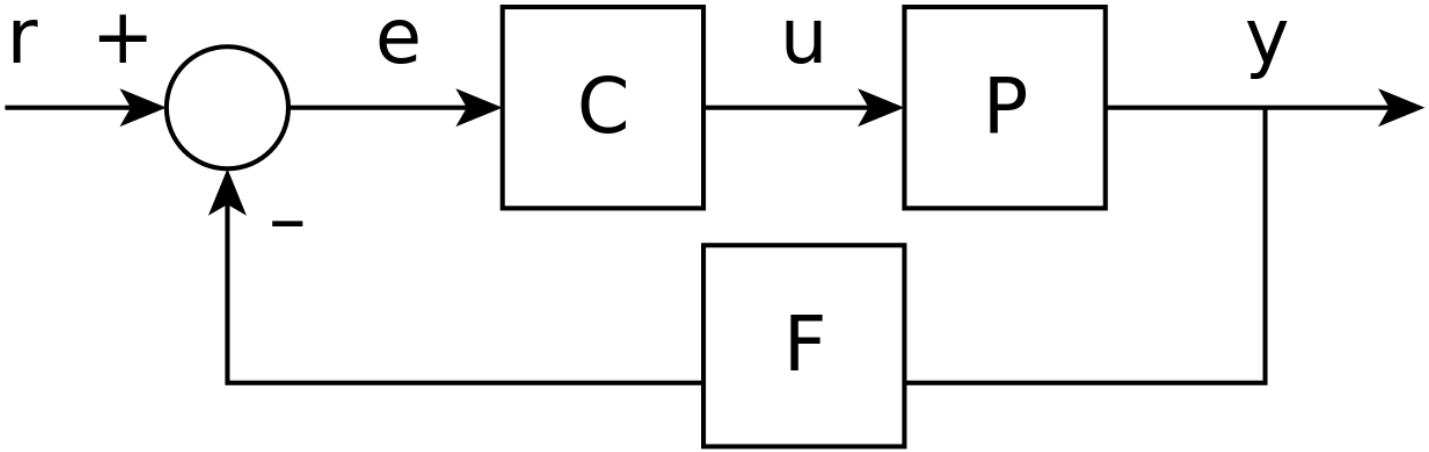
- Can’t be interacted with
- Dependent on time
- Lossy and lossless operators

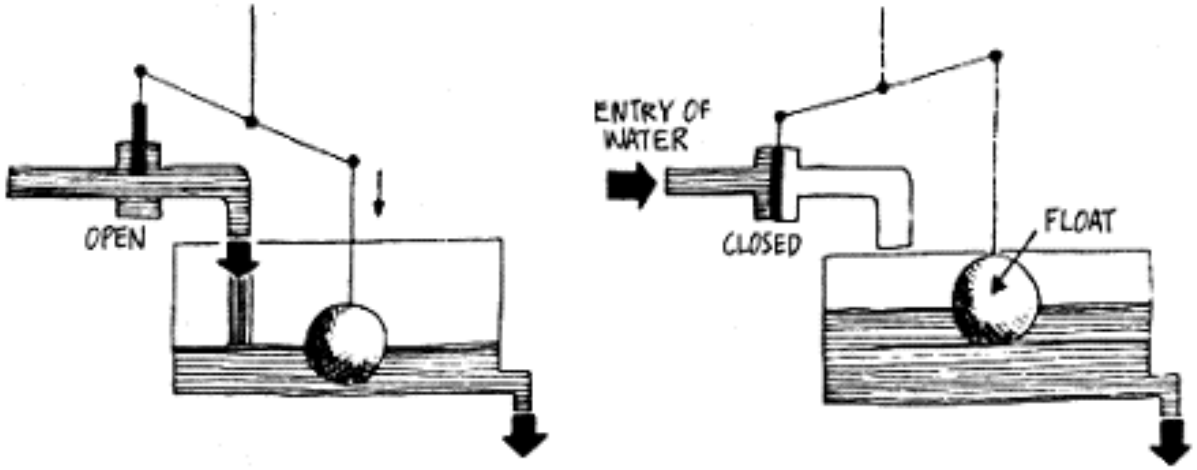
- **Our solution**
  - Move overproduction control to source
  - Keep the operators *reactive*
  - *Automatically calculate how much data to produce*

Feedback Control

Laplace transformation

$$Y(s) = \left(\frac{P(s)C(s)}{1 + F(s)P(s)C(s)} \right) R(s)$$

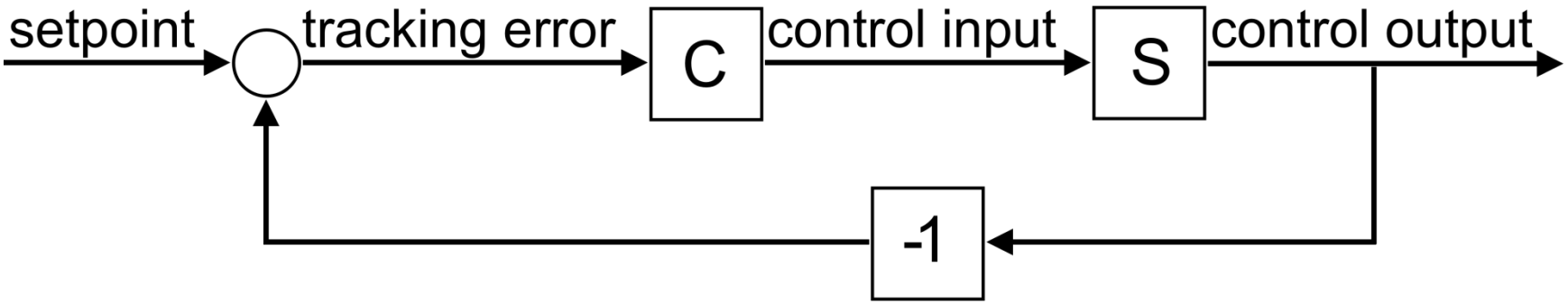



OPEN
ENTRY OF WATER
CLOSED
FLOAT


USA

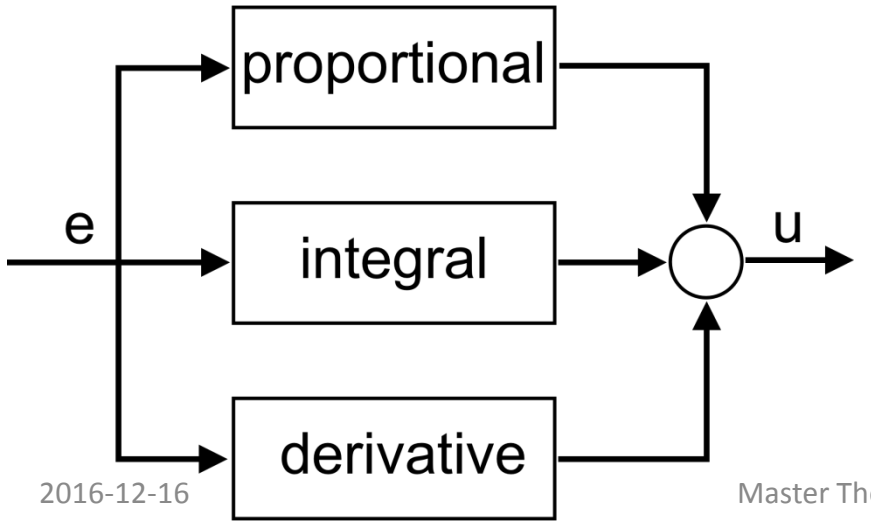

Honeywell
Indoor
72°
6:30 PM
Cool
Setting
72°
HOLD
Set
Clock/Day
Schedule
Fan
Auto
System
Cool
More

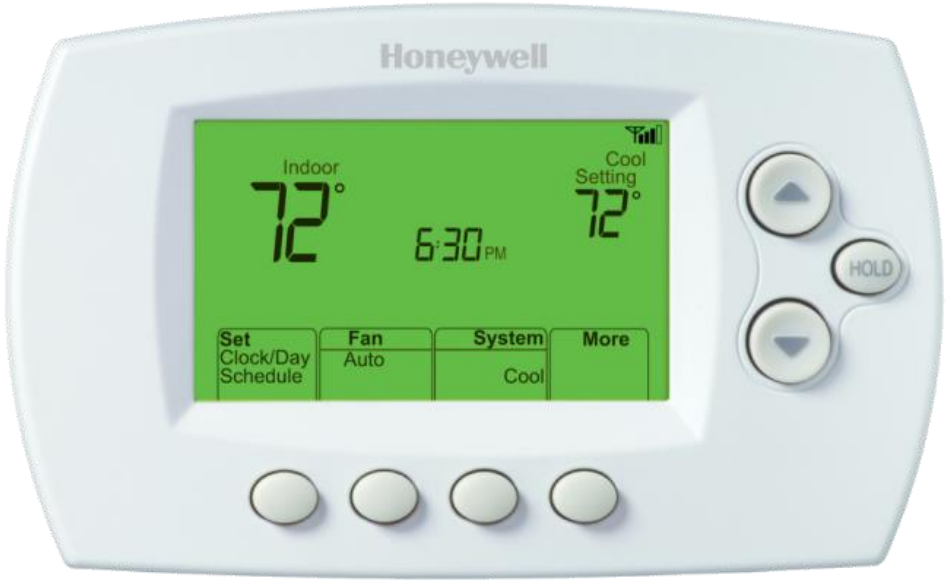
Feedback system



PID controller

$$u(t) = k_p \cdot e(t) + k_i \int_0^t e(\tau)d\tau + k_d \cdot \frac{\mathrm{d}e(t)}{\mathrm{d}t}$$





feedback4s

Components are transformations over *Observables*:

```
class Component[I, O](transform: Observable[I] => Observable[O]) {
    def run(is: Observable[I]): Observable[O] = transform(is)

    def >>>[X](other: Component[O, X]): Component[I, X] =
        Component(other.run _ compose this.run)

    def map[X](f: O => X): Component[I, X] = this >>> create(f)

    // many more operators
}
object Component {
    def create[I, O](f: I => O): Component[I, O] =
        new Component(_ map f)
}
```

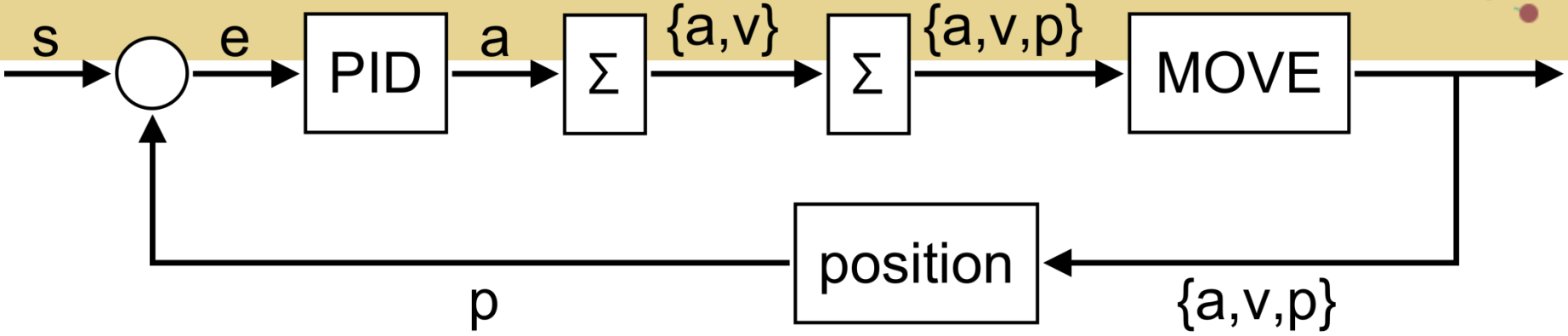
feedback4s

```
<dependency>
  <groupId>com.github.rvanheest</groupId>
  <artifactId>feedback4s</artifactId>
  <version>1.0</version>
</dependency>
```

https://github.com/rvanheest/feedback4s

http://doi.org/10.5281/zenodo.169095

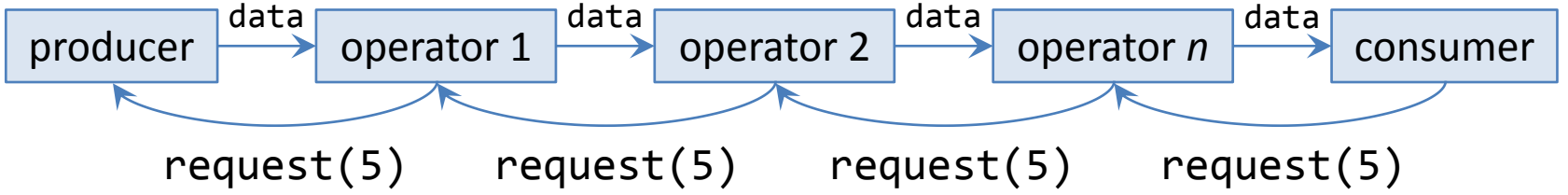
Demo

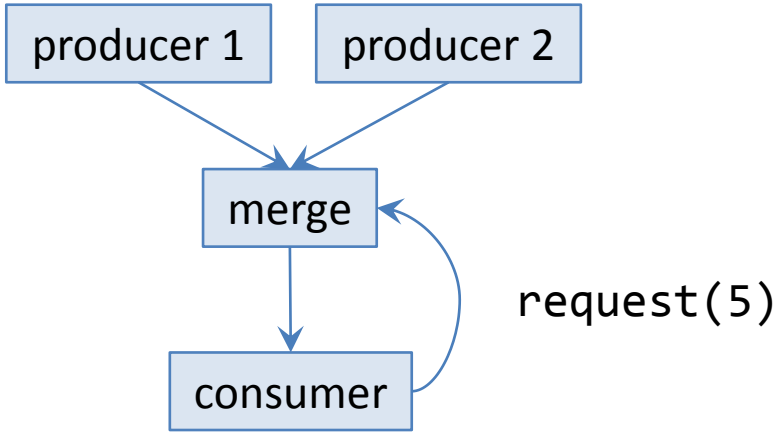


Feedback applied to overproduction

- Overproduction: fast producer, slow consumer
- Hot source: can’t be interacted with
  - Lossy & lossless operators
- Cold source: can be interacted with
  - Backpressure

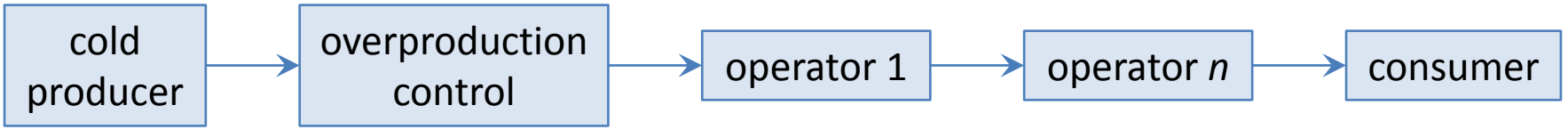
Backpressure/Reactive Streams





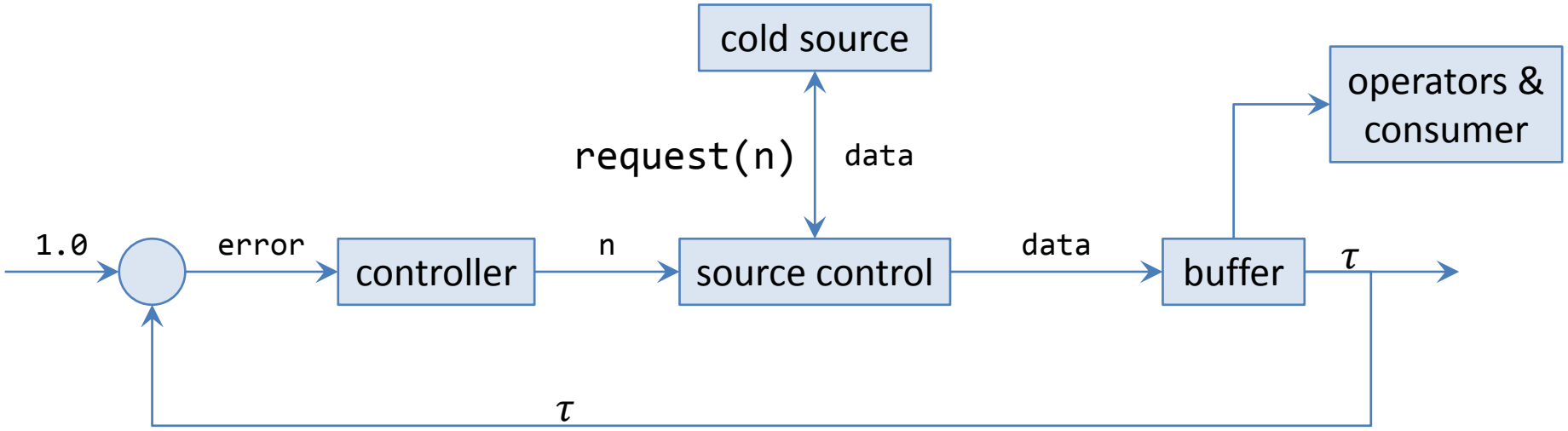

```
producer1.merge(producer2)
  .subscribe(println(_))
```

'*Backpressure*' in the source



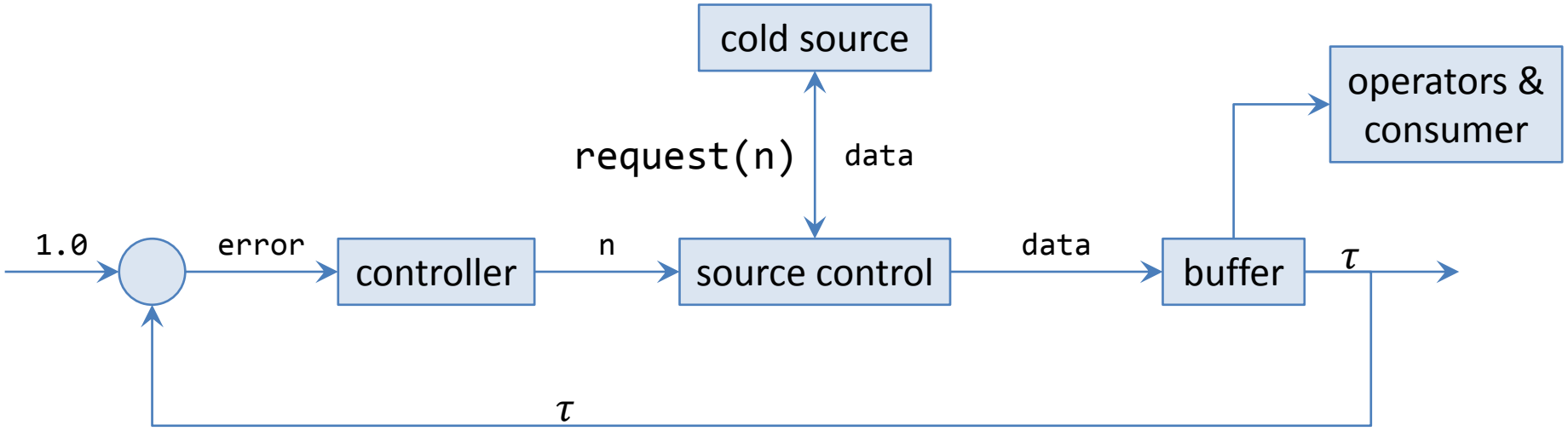
- Overproduction control where it is handled best:
  - **In the source**
- Everything after that is considered to be hot!

Overproduction feedback system



- Metrics
  - #elements in buffer
  - throughput

Overproduction feedback system



- Throughput
  - $\tau_t = \frac{q_{t-1}+n_t-q_t}{q_{t-1}+n_t} = 1 - \frac{q_t}{q_{t-1}+n_t}$ with q_{t-1}, q_t, n_t integers ≥ 0
  - $0.0 \leq \tau_t \leq 1.0$

Overproduction in Rx

```
trait Requestable[T] {
 protected final val subject = PublishSubject[T]()

 final def results: Observable[T] = subject

 def request(n: Int): Unit
}

object Requestable {
  implicit class ReqObs[T](val requestable: Requestable[T]) {
    def observe(timeout: Duration = 1 milli): Observable[T] = …
  }
}
```

Overproduction in Rx

```
Requestable.from(0 until 133701)
  .observe
  .filter(_ % 2 == 0)
  .map(2 *)
  .drop(10)
  .take(20)
  .subscribe(i => println(s"> $i"))
```

Overproduction in Rx

```
> 40
> 44
> 48
> 52
> 56
> 60
> 64
> 68
> 72
…
```

Compared to backpressure

- Wrap cold source in reactive programming model
- Overproduction safety
- Source + feedback system = hot
- Operators can be implemented purely reactively

Main achievements

- Analysis of sources and existing solutions for overproduction
- feedback4s
- Reactive solution to overproduction for cold sources