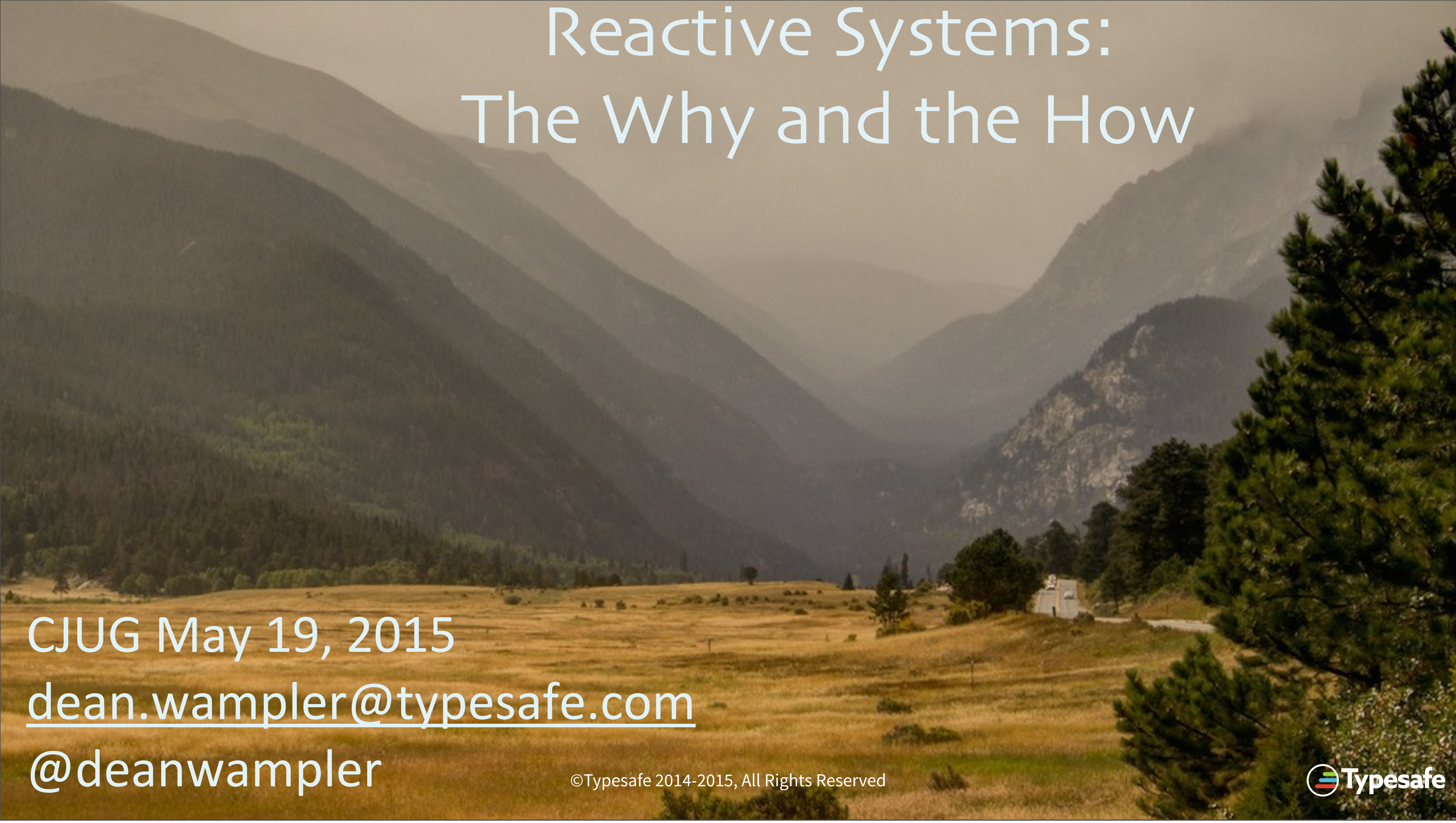
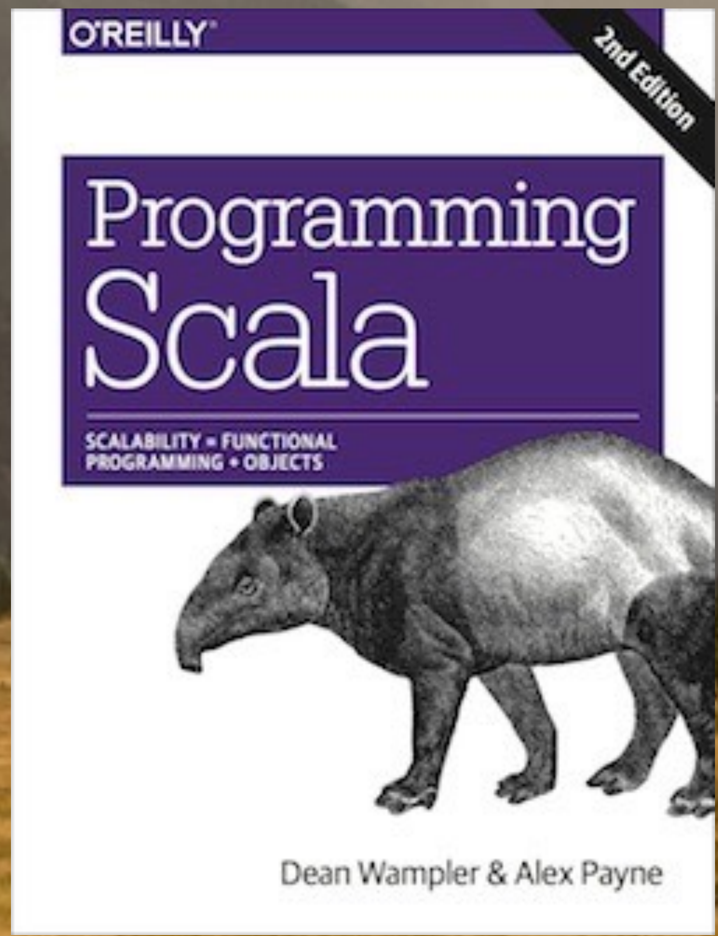


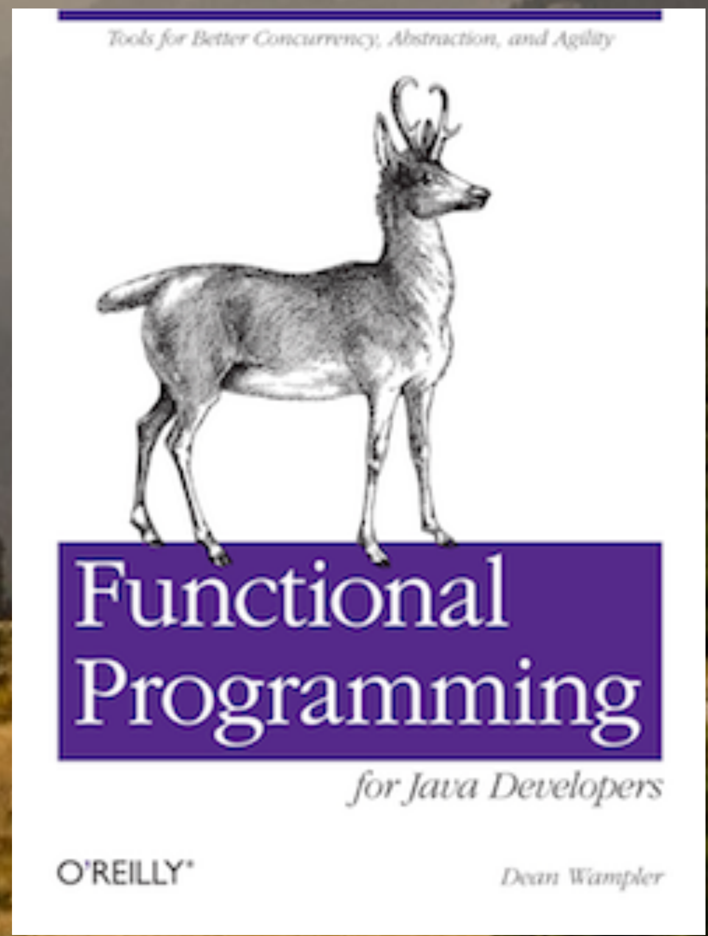
Photos from Colorado, Sept. 2014.

dean.wampler@typesafe.com

polyglotprogramming.com/talks

@deanwampler





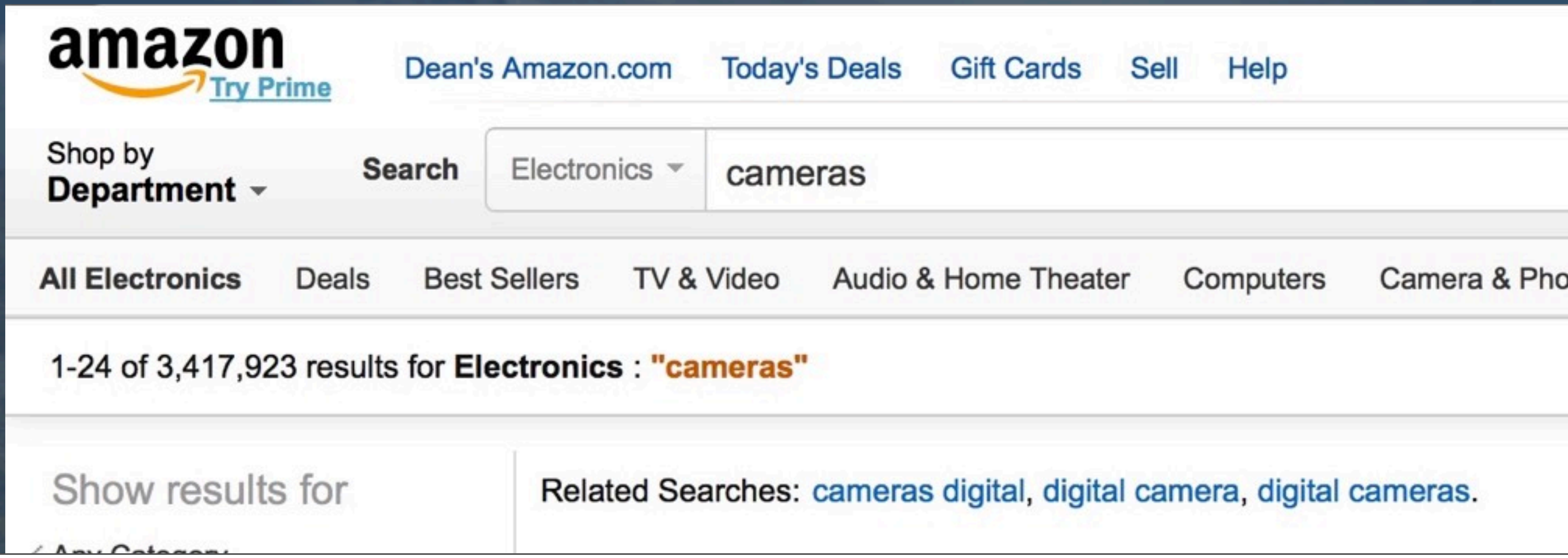
Tuesday, May 19, 15

I founded CASE, I lead the Spark Users group, and I’m a co-organizer of CHUG.

Tuesday, May 19, 15

Let’s motivate the notion of “reactive” systems by exploring some common scenarios we see today.

Cyber Monday?

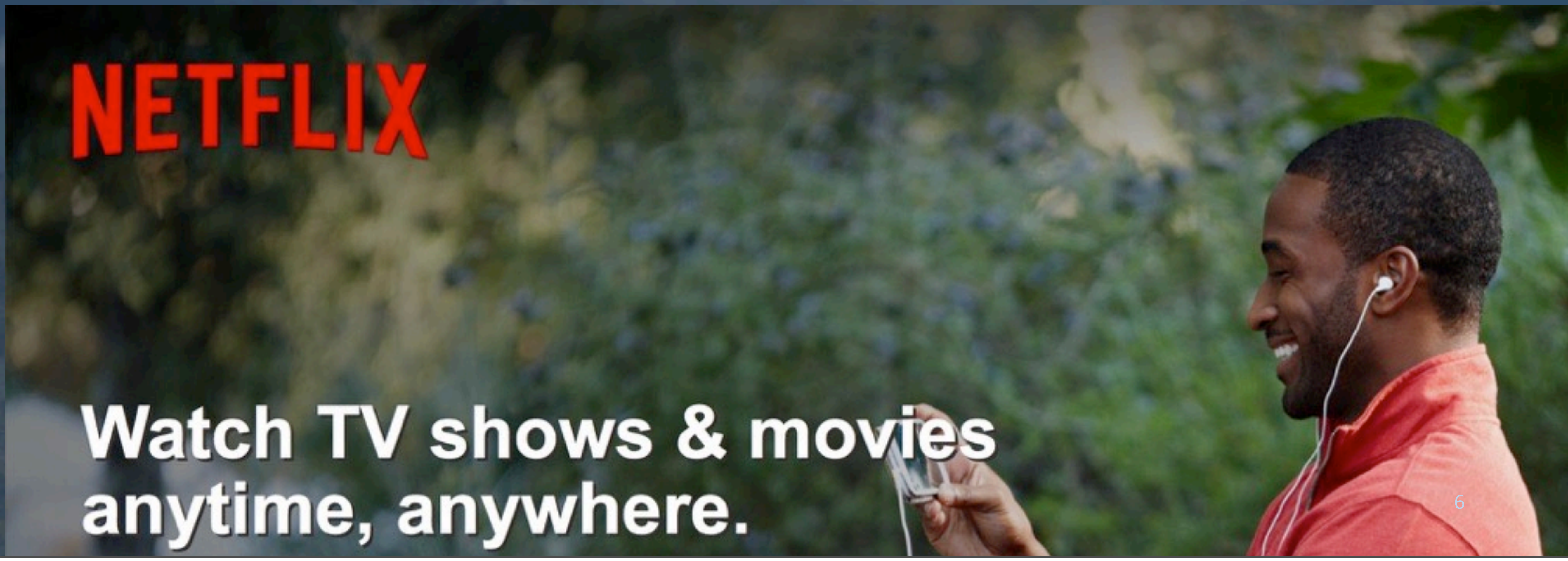


Tuesday, May 19, 15

Your online store needs to scale up and down with demand. It needs to degrade gracefully if some service components are lost or disconnected by a network partition. For example, if the canonical catalog “disappears” behind a network partition, it’s probably better to continue selling with a stale local copy.

photo: Amazon home page, http://amazon.com.

On demand?



Netflix has extreme scale challenges, but they have become an innovator in building highly resilient, scalable services.
What happens when a new season of “House of Cards” is released? Spikes in traffic?
photo: Netflix home page, http://netflix.com.

Internet of Things has several categories of applications, each of which has needs that motivate reactive programming.

Medical Devices, IT Systems

Phone home:

- Upload data
  - Usage patterns
  - Predictive diagnostics
- Fetch patches

Medical devices upload test results (e.g., ultrasound images and video) to servers. Med. devices and IT systems send requests for automated updates, send the equivalent of “click-stream” data used to assess usability, etc., and increasingly send metrics used to predict potential HW failures or other service needs.
ultrasound photo: http://www.usa.philips.com/healthcare-product/HC795054/hd11-xe-ultrasound-system
switch photo: http://networklessons.com/switching/introduction-to-vtp-vlan-trunking-protocol/

Medical Devices, IT Systems

Characteristics:

- Stable to intermittent network connectivity
- One way and two way
- Mixed bandwidth

A mobile scanner might move in and out of WiFi zones, so caching data is necessary. IT appliances are (hopefully) always online. Some data is one way, like diagnostic info for predictive analytics, while data uploads and patch requests need acknowledgements. Bandwidth can vary.

Aircraft Engines

Phone home:

- Upload telemetry
  - Predictive diagnostics
  - Redundant tracking data!

Tuesday, May 19, 15

Each engine collects 0.5-1TB of data per flight. Most is currently tossed! Our only clue about the final resting place of Malaysian Airlines Flight 370 was engine telemetry picked up by satellites and used to analyze possible routes.

Trucks, Farm Equipment

GPS Tracking:

- Optimize routing, fuel use, etc.
- Spy on drivers?
- Per plant tracking!

Track data to optimize routing, minimize fuel use with shortest path and/or delivering heaviest items first. Ensure drivers are obeying the rules of the road and company policies. Some farm equipment planting, watering, and fertilizing gear now tracks data per plant!

UPS truck photo: http://en.wikipedia.org/wiki/United_Parcel_Service

Planter/seeder photo: http://www.deere.com/en_US/products/equipment/planting_and_seeding_equipment/planting_and_seeding_equipment.page?

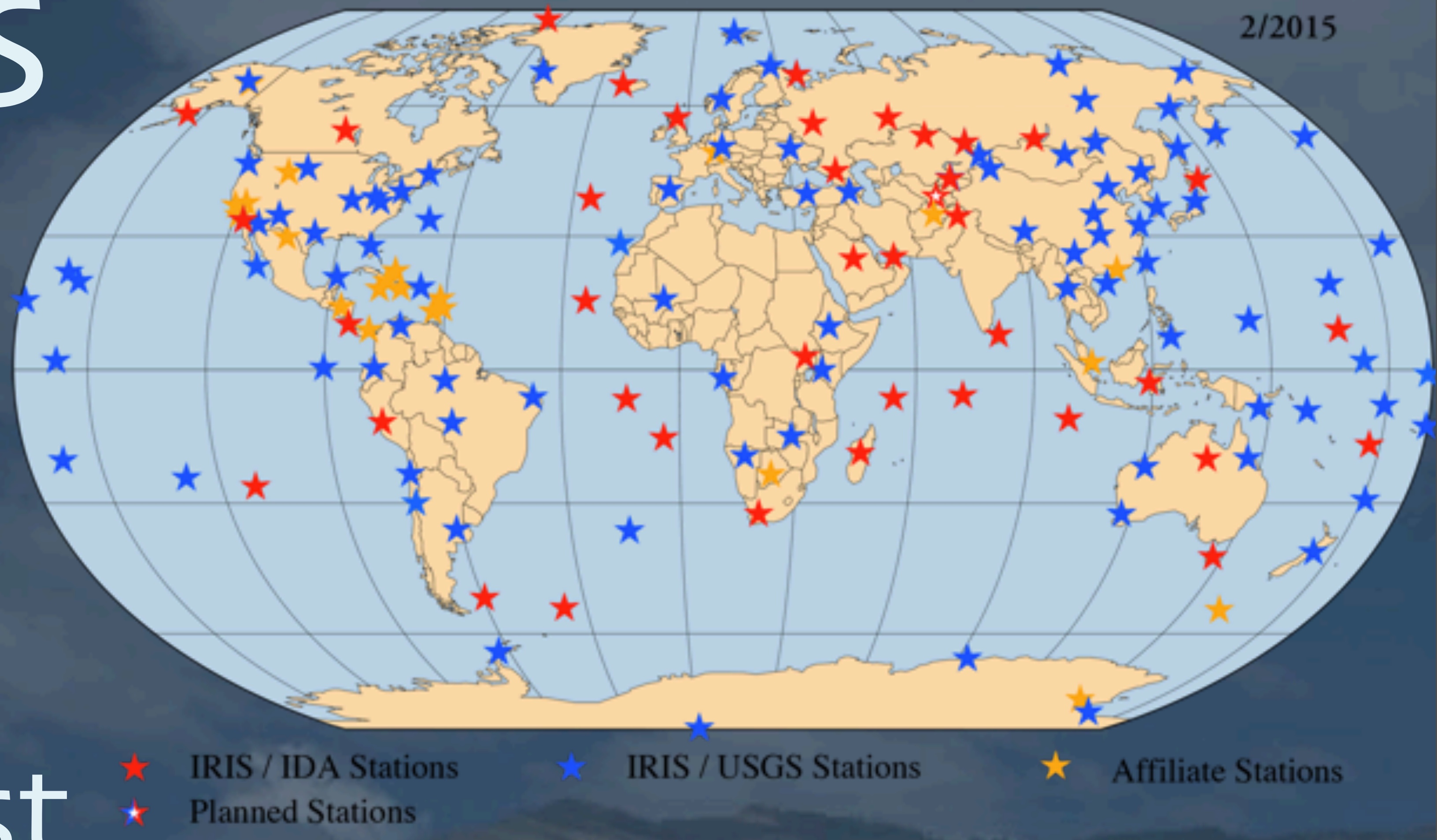
Trucks, Farm Equipment

Connectivity:

- Always along roads
- Intermittent on farms (WiFi in barns?)

Some rural areas don't have sufficient wireless data coverage for farm equipment to remain to online full time.

Remote Sensors



Human to Real-time Responsiveness:

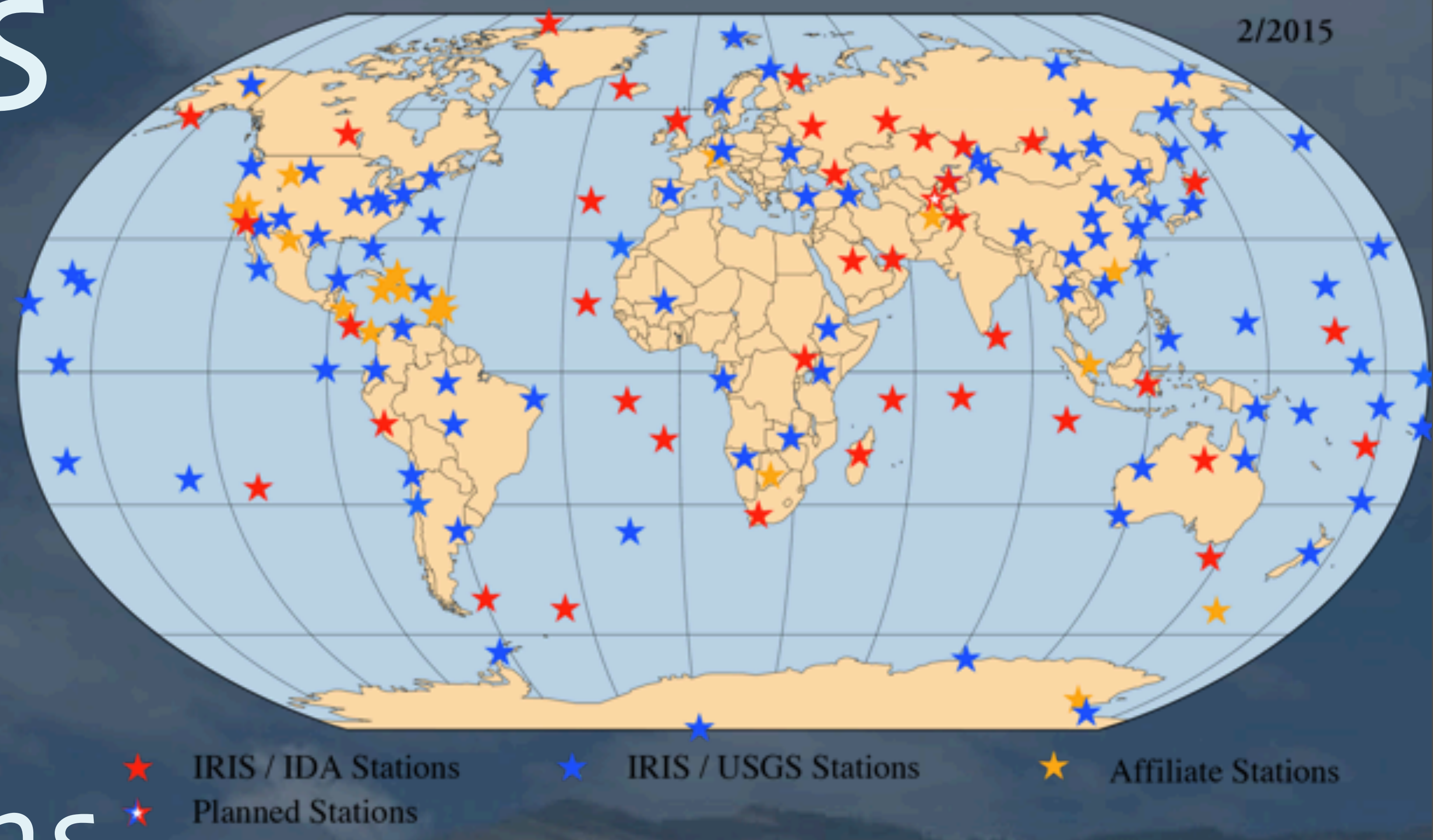
- Earthquake, nuclear test sensor networks.
- Climate change monitoring

For earthquake sensor networks, you want to get the information to emergency services and community alarm systems in milliseconds.
photo: http://www.iris.edu/hq/programs/gsn

Remote Sensors

Characteristics:

- Redundant sensors
- Low-latency connections
- Low-bandwidth requirements



Tuesday, May 19, 15

This requires redundant sensors, always on connectivity, and low-latency connections. The amount of data isn't large. Some networks, like monitoring rainfall or glaciers for climate change studies, might be offline except for once-per-year downloads done onsite!

Robotics

Connectivity:

- Two-way, but time of flight matters!
- Autonomous?

Some rural areas don't have sufficient wireless data coverage for farm robots to remain to online full time. The one-way time of flight between Earth and Mars is ~8 minutes.
Quadcopter photo: http://www.dji.com/product/phantom
Mars rover photo: http://en.wikipedia.org/wiki/Mars_Exploration_Rover

Health Monitoring

Characteristics:

- Occasional to always-on connectivity
- Detect health emergencies: call for help?

Tuesday, May 19, 15

Health monitoring tools are most popular for gathering activity data and some vital signs for analysis later. Some monitors are designed to detect medical emergencies and call for help when needed.
photo: http://www.fitbit.com/force

Home Automation

Characteristics:

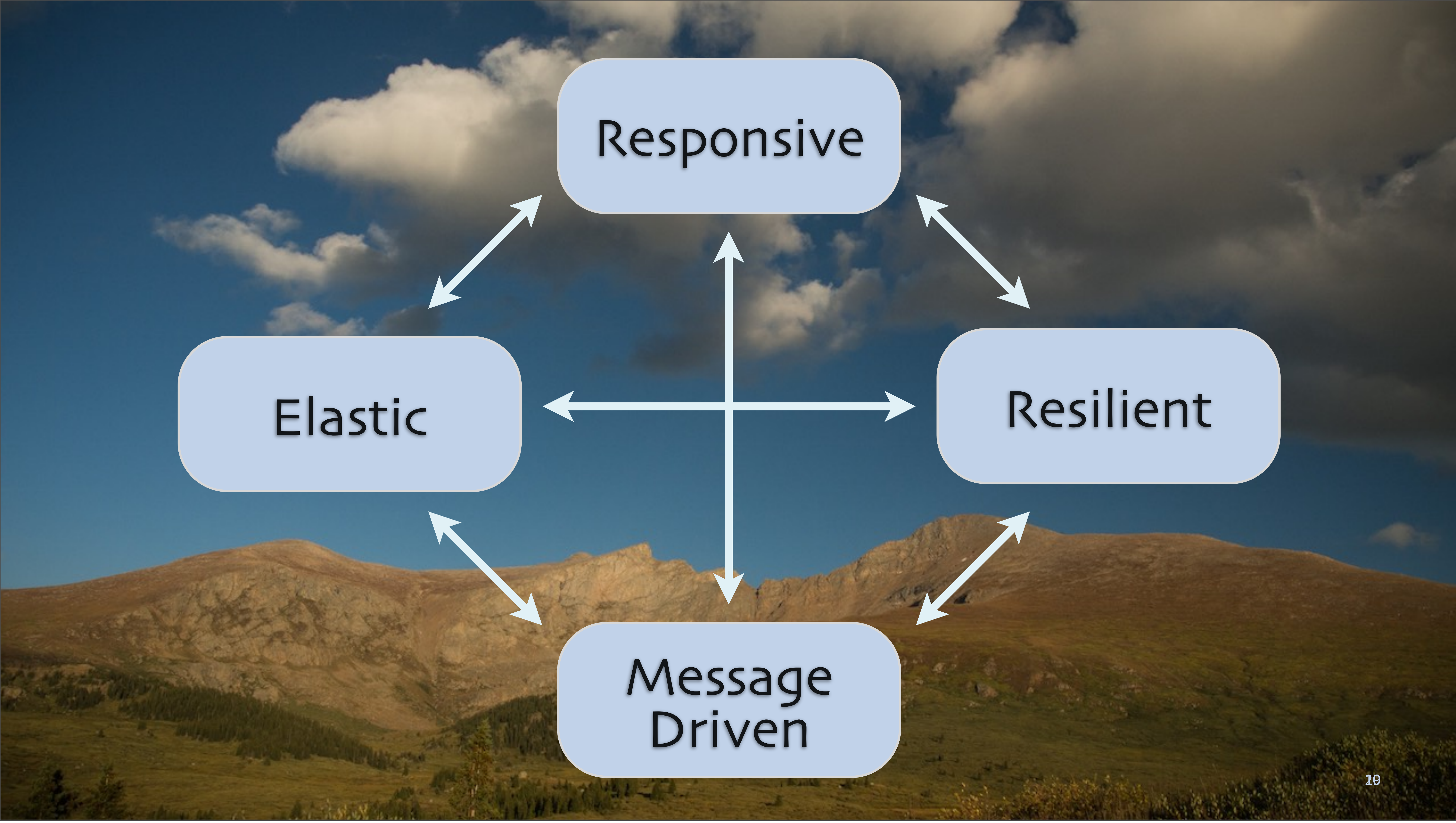
- ToD packet storms
- Fire & break-in detection: automatic notification of authorities

Tuesday, May 19, 15

These systems are subject to time of day packet storms, e.g., while everyone in a given time zone is waking up or going to bed.
photo: https://store.nest.com/product/thermostat/

Tuesday, May 19, 15

The idea of Reactive Systems emerged to catalog several common characteristics of the systems we have to build to support these scenarios, without over-specifying how these characteristics are satisfied.



The four characteristics or traits of Reactive Systems... as articulated by the Reactive Manifesto, which attempts to codify lessons learned across many projects, industries, and years building highly available, scalable, and reliable systems.

Tuesday, May 19, 15

The four characteristics of Reactive Systems... as articulated by the Reactive Manifesto, which attempts to codify lessons learned across many projects, industries, and years building highly available, scalable, and reliable systems.

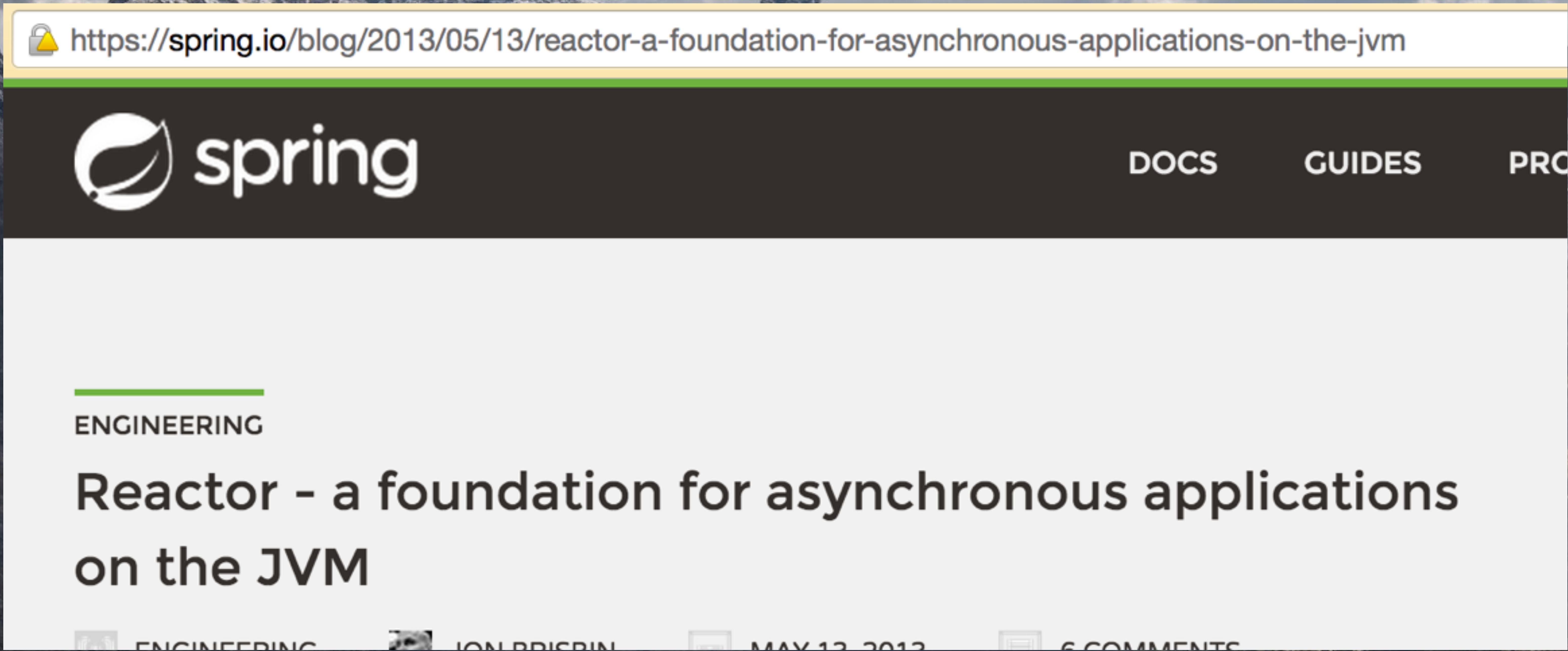
Before discussing them in detail, let’s slay some myths.

Tuesday, May 19, 15

The RM attempts to codify lessons learned over many years in many scenarios. It’s not new. It doesn’t claim to be new.

While Typesafe’s Jonas Bonér was one of the originators of the RM, other originators and contributions include experts in many companies and specialties.

Industry Adoption



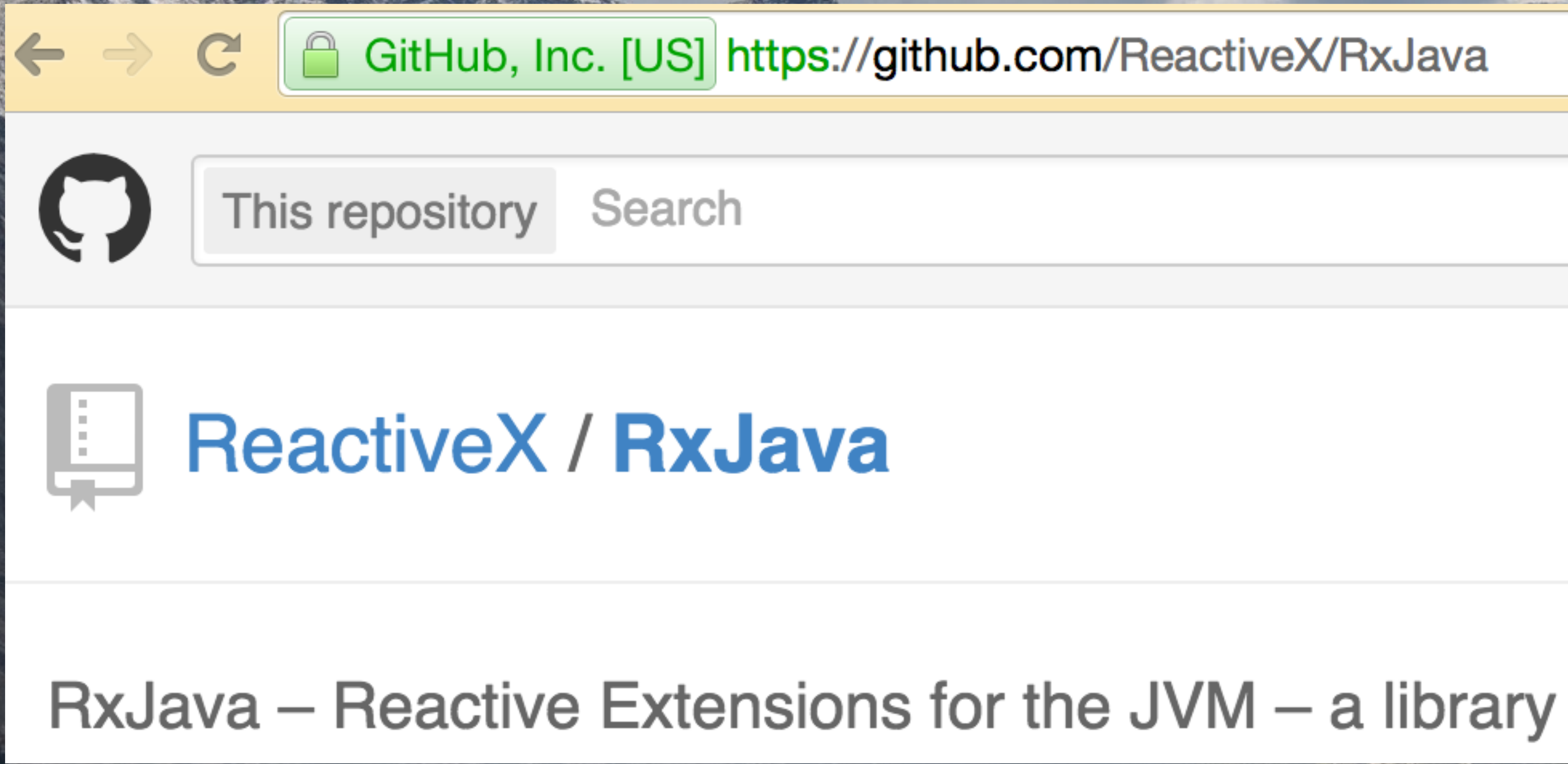
Tuesday, May 19, 15

A few industry heavyweights that are embracing Reactive. First, Spring's Reactor

Industry Adoption

Even Oracle is embracing Reactive principles for Java EE.

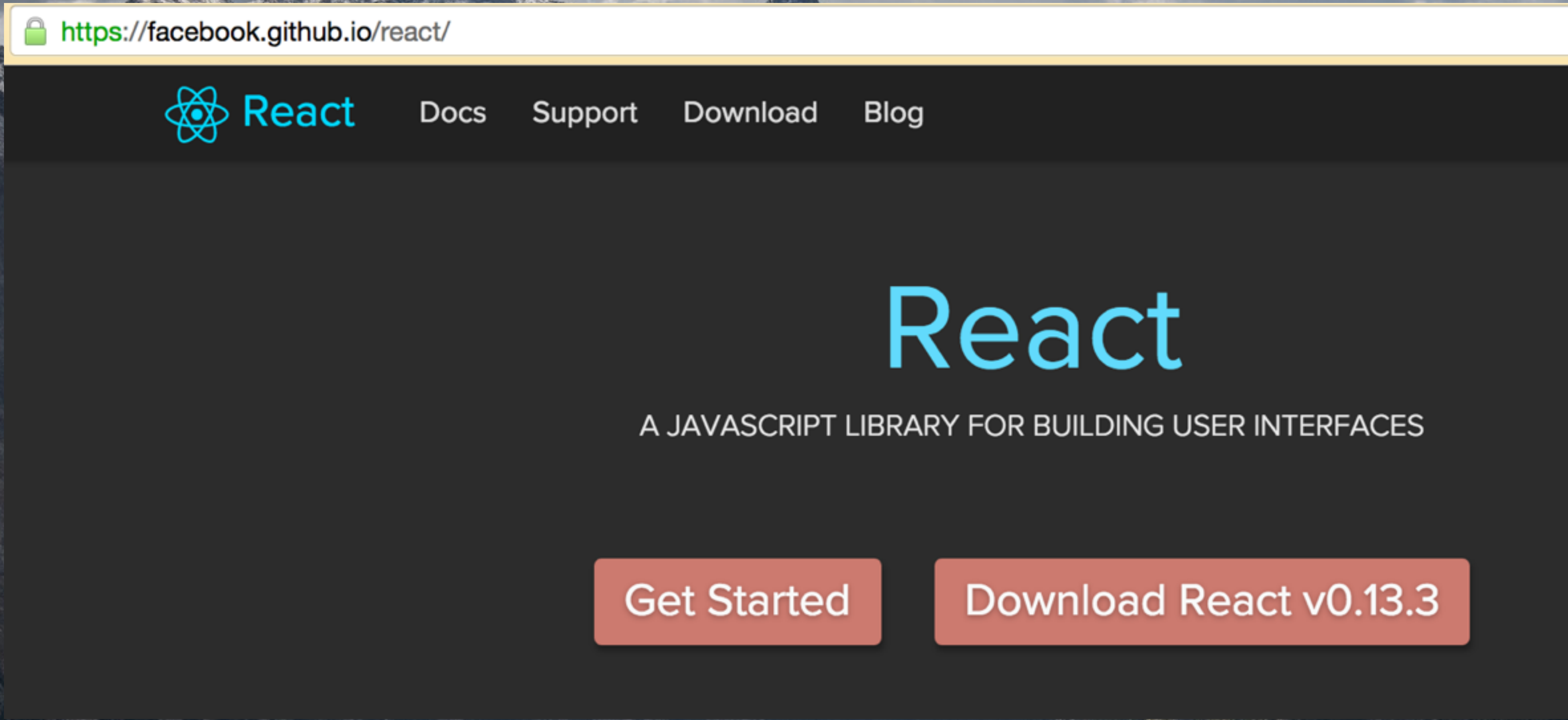
Industry Adoption



Tuesday, May 19, 15

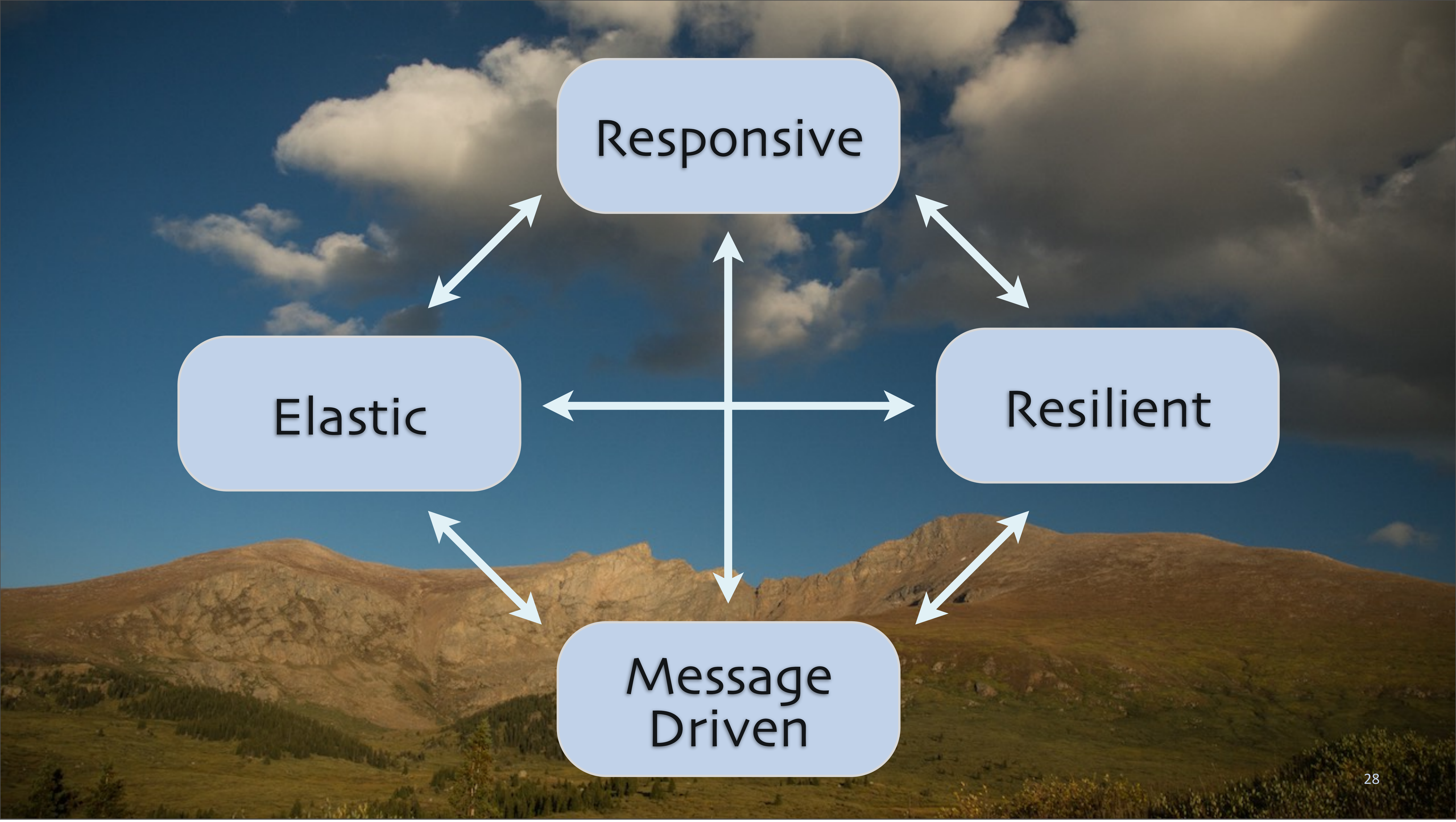
Netflix created RxJava. (We'll define "Reactive Extensions")

Industry Adoption



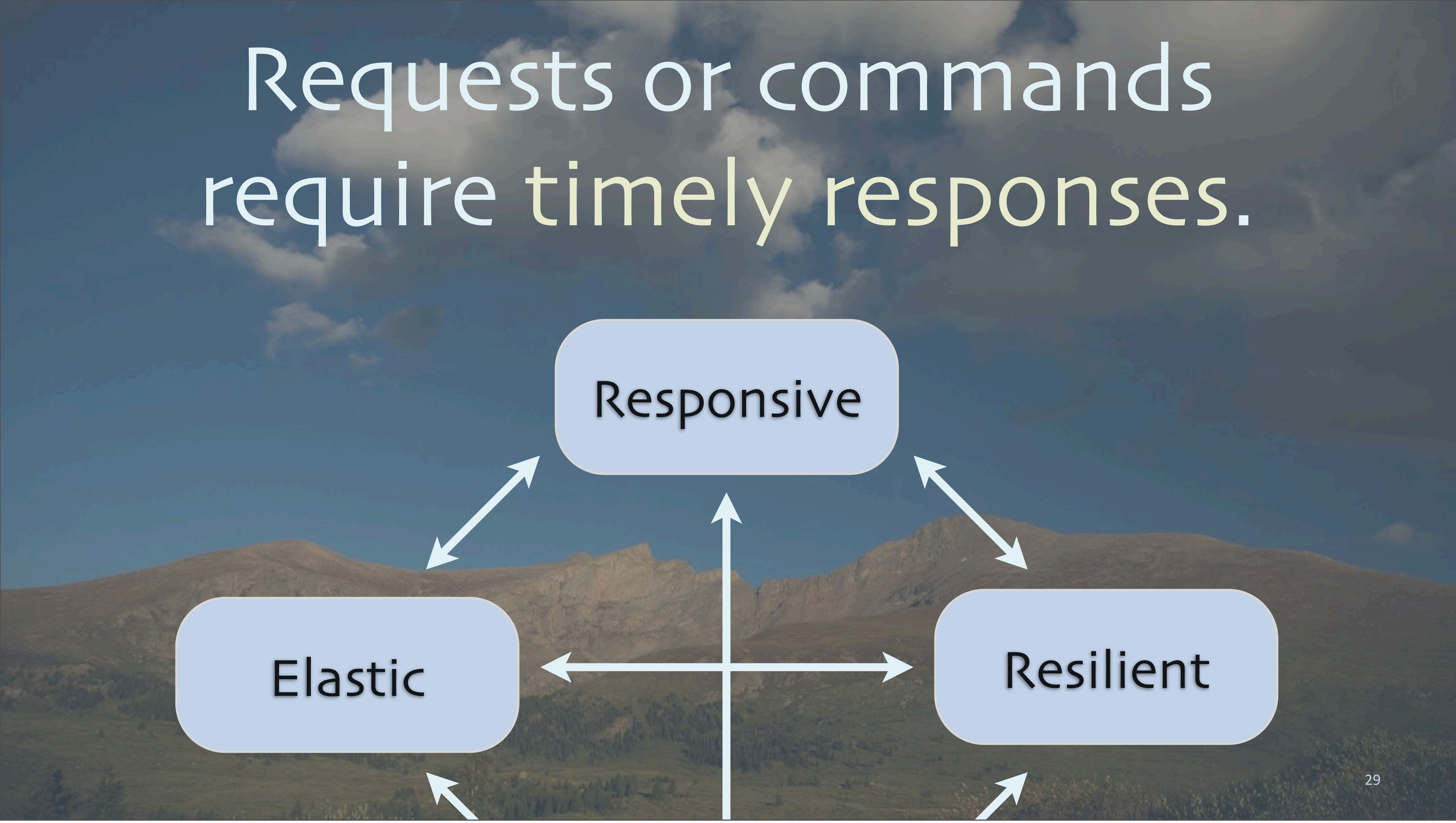
Tuesday, May 19, 15

Facebook's JS framework.



Tuesday, May 19, 15

Now let's explore the four traits of Reactive systems.



What does it mean if a service you rely on fails to respond to requests for service?


Responsive


Responsive
Cornerstone of
usability and utility.
31


Responsive
Requires rapid detection of errors and quick responses.
32


Responsive
Requires predictable
response times
and quality of service.
33

Tuesday, May 19, 15

You should plan in advance what level of service you’ll provide if (or better, when) certain failure scenarios arise.

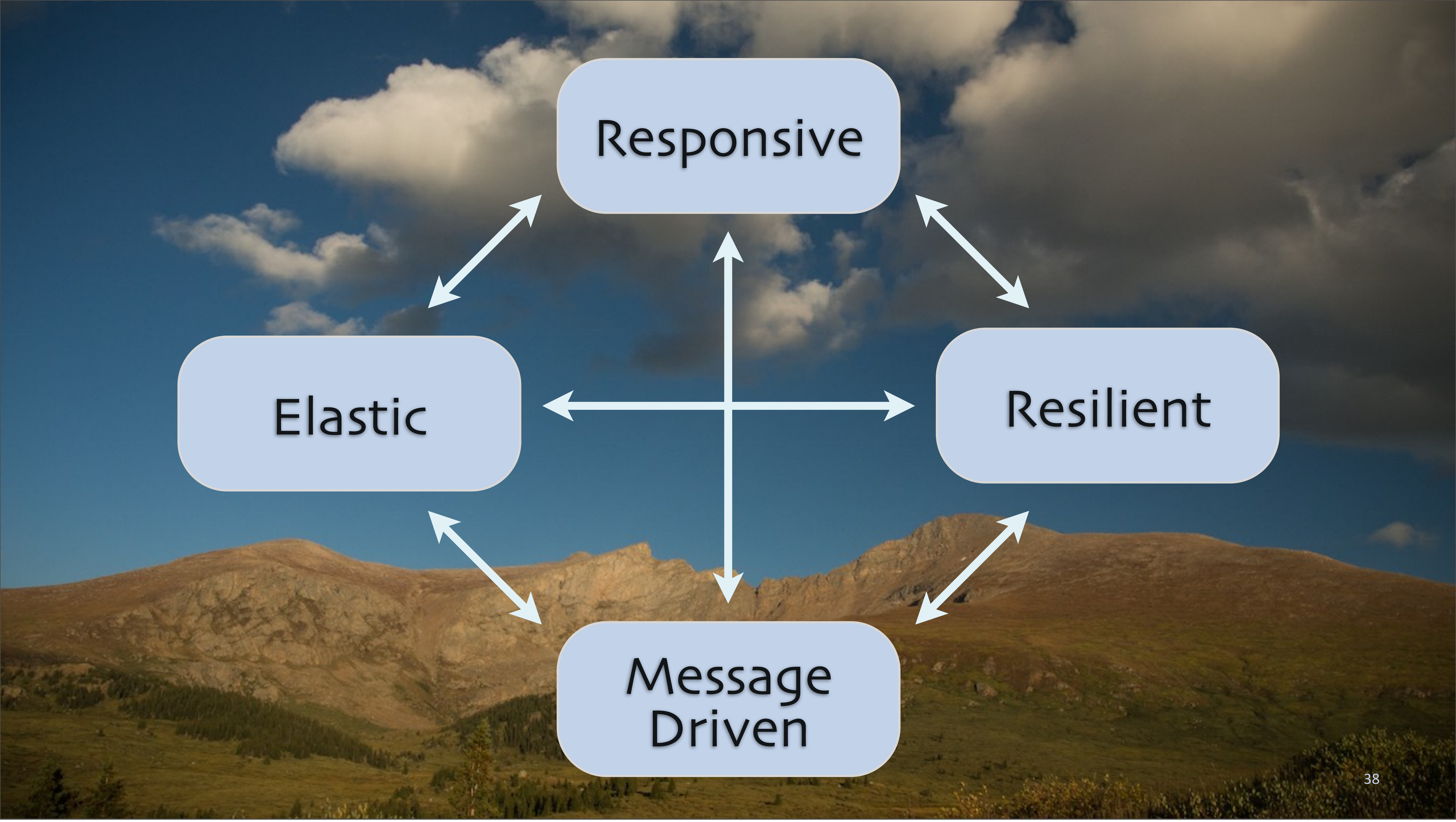
Tuesday, May 19, 15

You have to be a clock watcher of sorts.

Example:
Netflix Simian Army

For each trait, I'll cite some good examples of adding the trait. Image from http://devops.com/features/netflix-the-simian-army-and-the-culture-of-freedom-and-responsibility/


Clobber services, servers,
even data centers
in production,
to verify service continuity.
37


Responsive
Elastic
Resilient
Message Driven

Tuesday, May 19, 15

Truly resilient systems must treat failures as routine, in some sense of the word, because they are inevitable when the systems are big enough and run long enough.


Resilient

Tuesday, May 19, 15


Resilient
Failure is expected.
42

A normal part of your domain model, implementation, etc.

Tuesday, May 19, 15

Replication - other copies (data and services) replaced lost copies.
Containment and isolation - firewalls stop disaster from spreading.
Delegation - indirection to allow new copies to step into “holes”.

Tuesday, May 19, 15

We’ll see an example of what I mean.

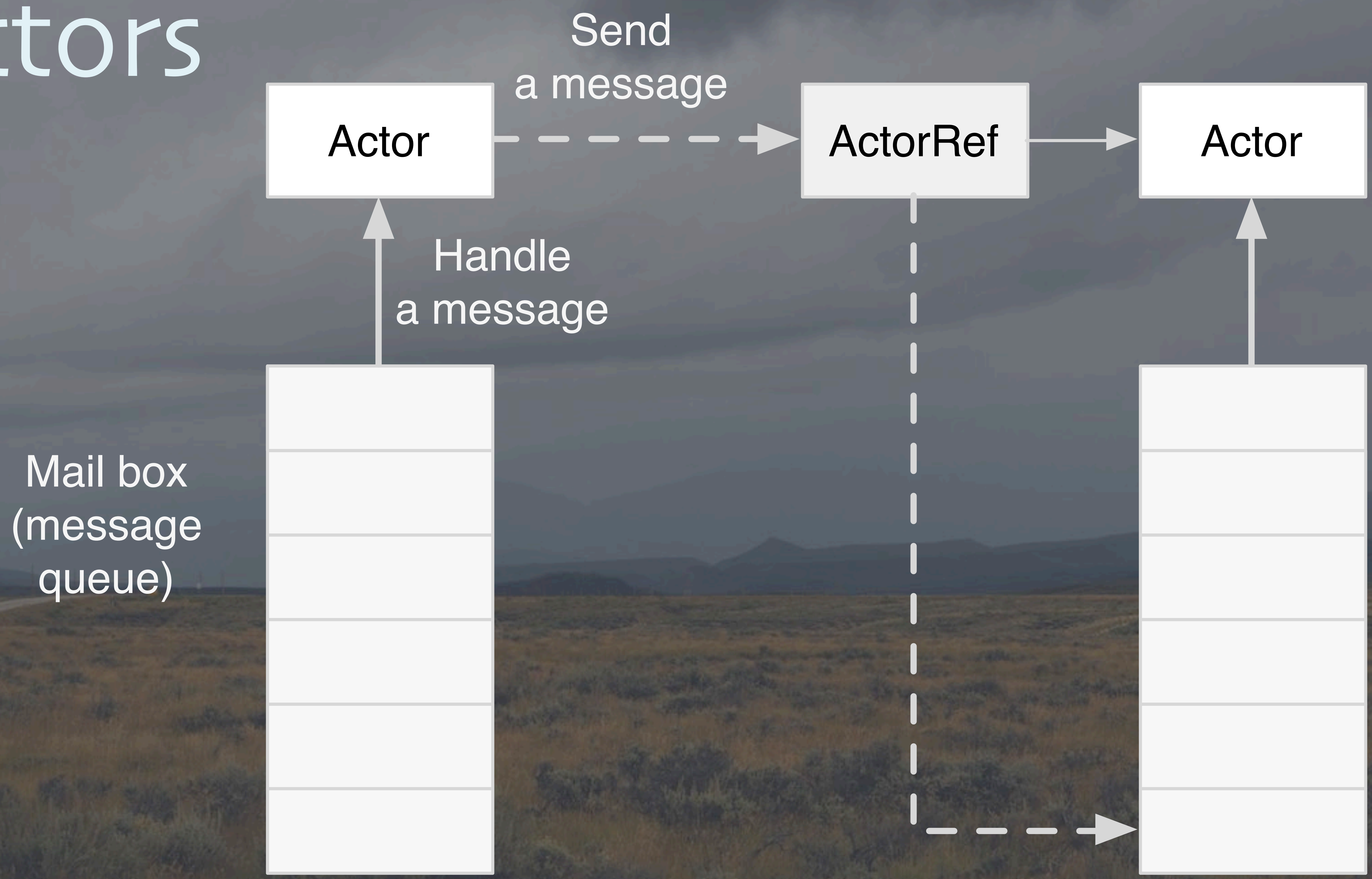
Tuesday, May 19, 15

The Netflix Simian Army could also be cited here.
We’ll come back and fill in details of Actor systems shortly. For now, let’s focus on error handling.

Tuesday, May 19, 15

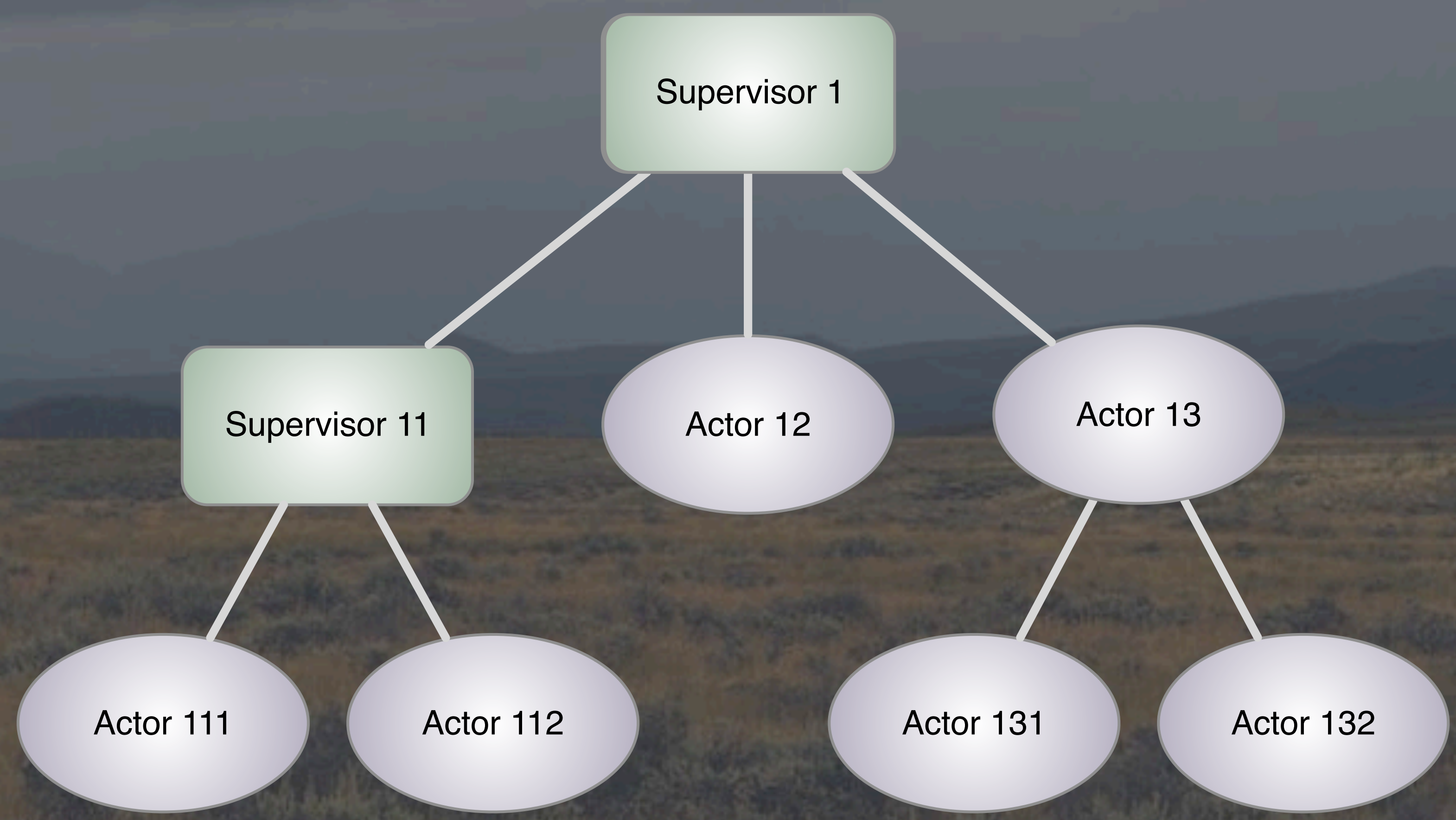
Rather than attempt to recover from errors inside the domain logic (e.g., elaborate exception handling), allow services to fail, but with failure detection and reconstruction of those services, plus failover to other replicas.

Actors



Actors are similar to objects in Smalltalk and similar, message-passing systems; autonomous agents with defined boundaries that communicate through message passing. Actors, though process each message in a threadsafe way, so they are great for concurrency. (This diagram illustrates the Akka implementation - http://akka.io)

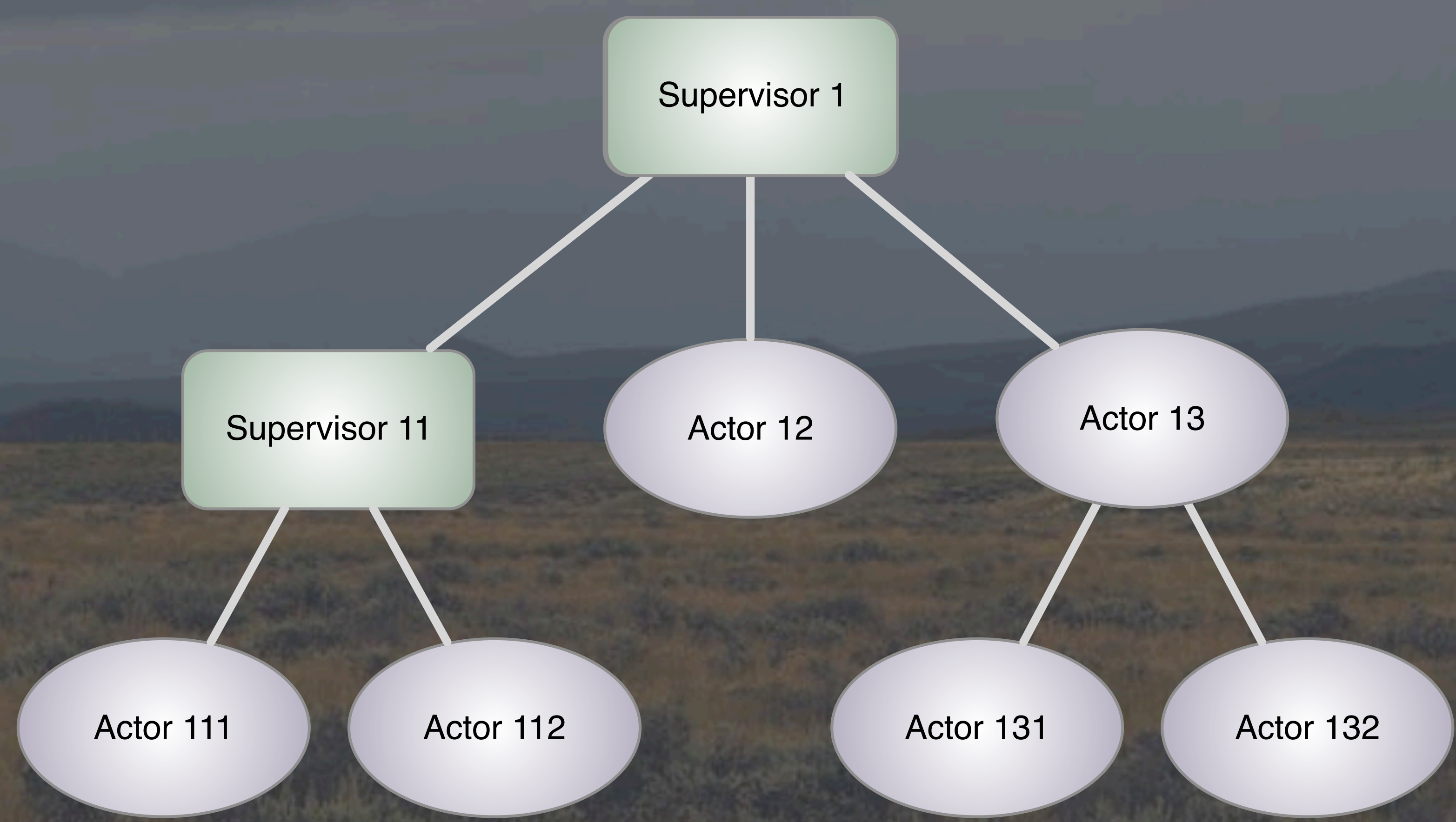
Erlang introduced supervisors. A hierarchy of actors that manage each “worker” actor’s lifecycle.



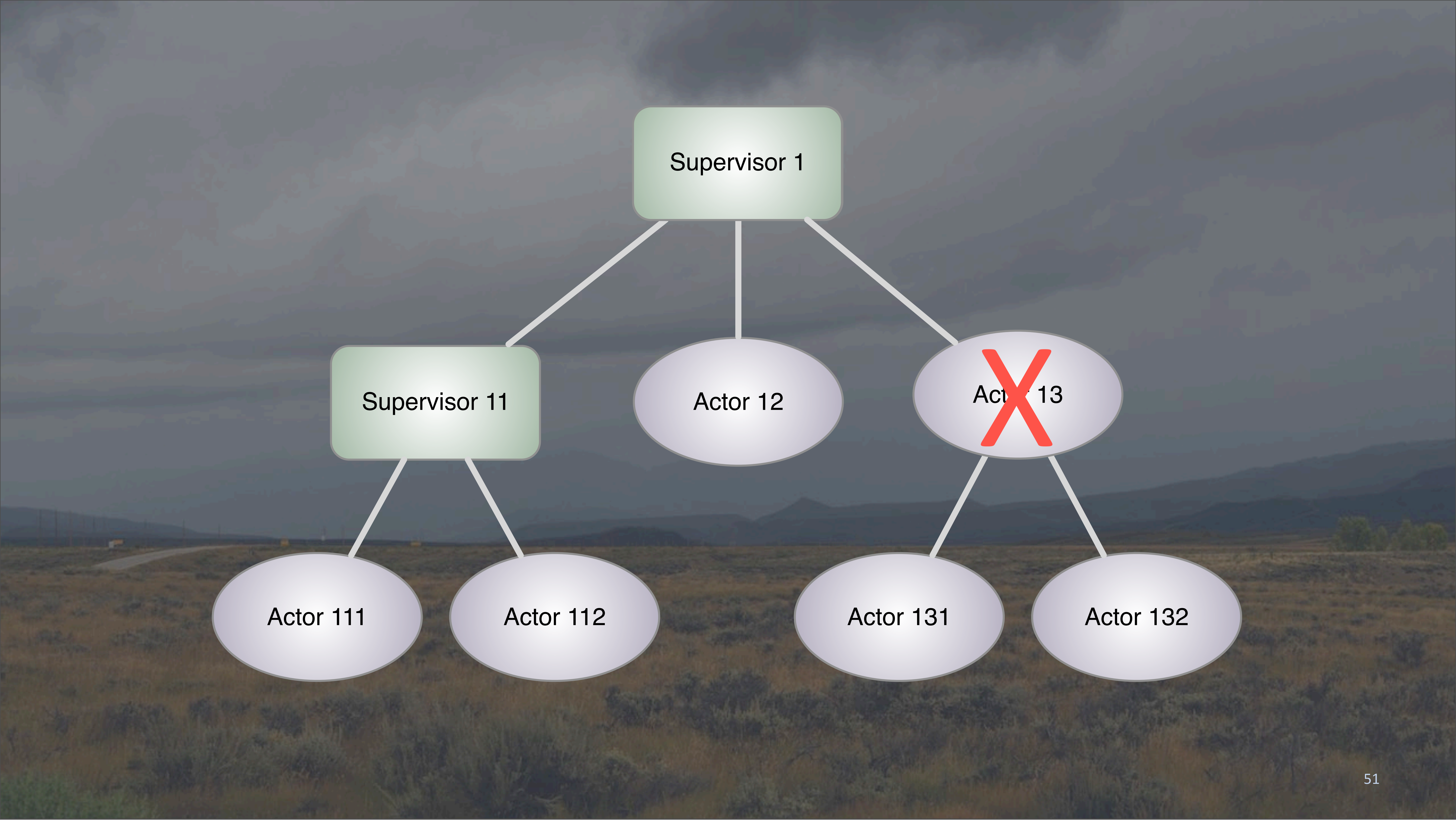
Tuesday, May 19, 15

There are lots of so-called Actor systems, but be wary of them unless they have this sophisticated supervision model or something like it (even though the original Actor model of Hewitt, et al., didn’t include supervision like this...).

Generalizes nicely to distributed actor systems.

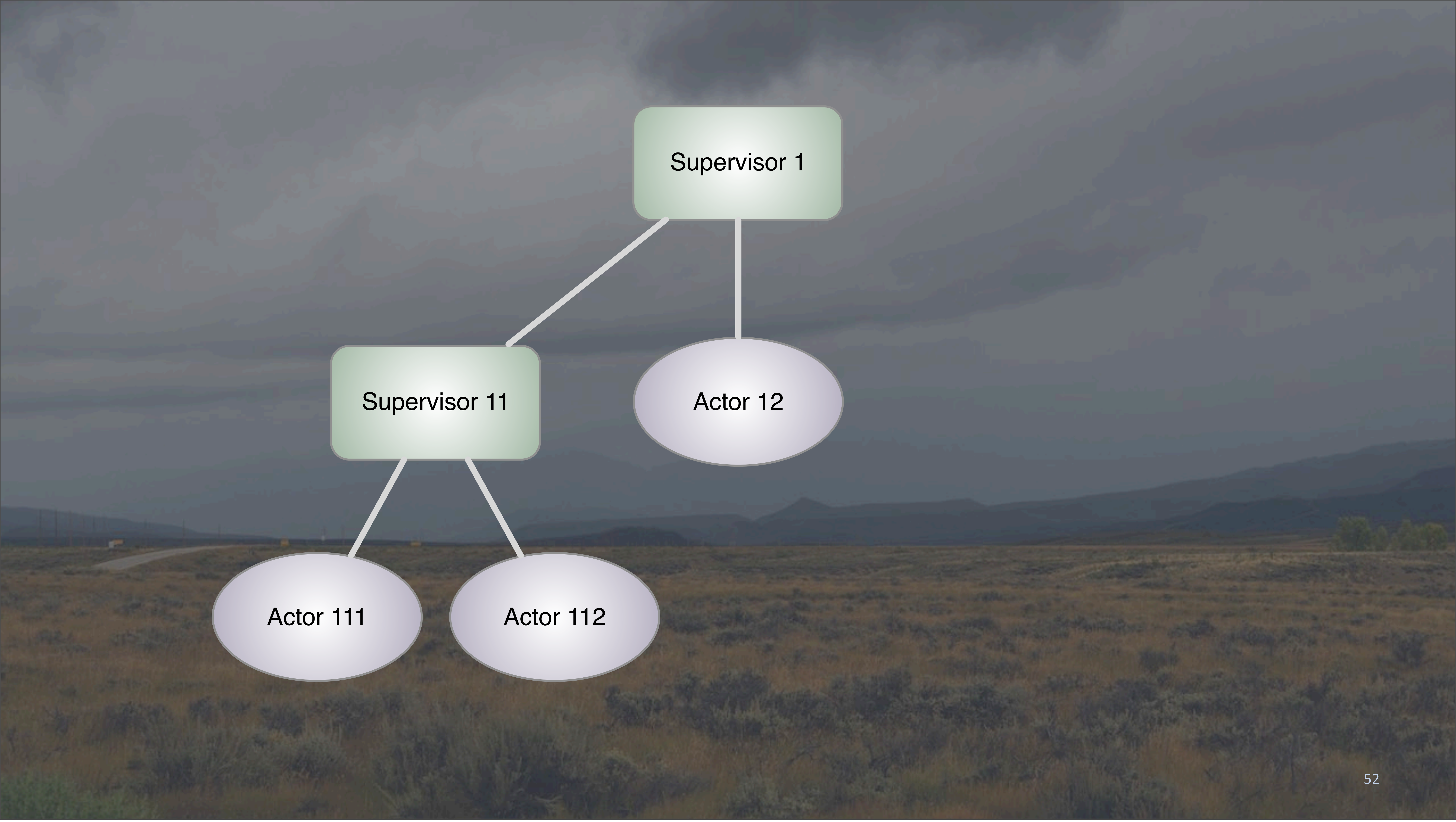


Uniform abstraction when the lines cross process and machine boundaries.



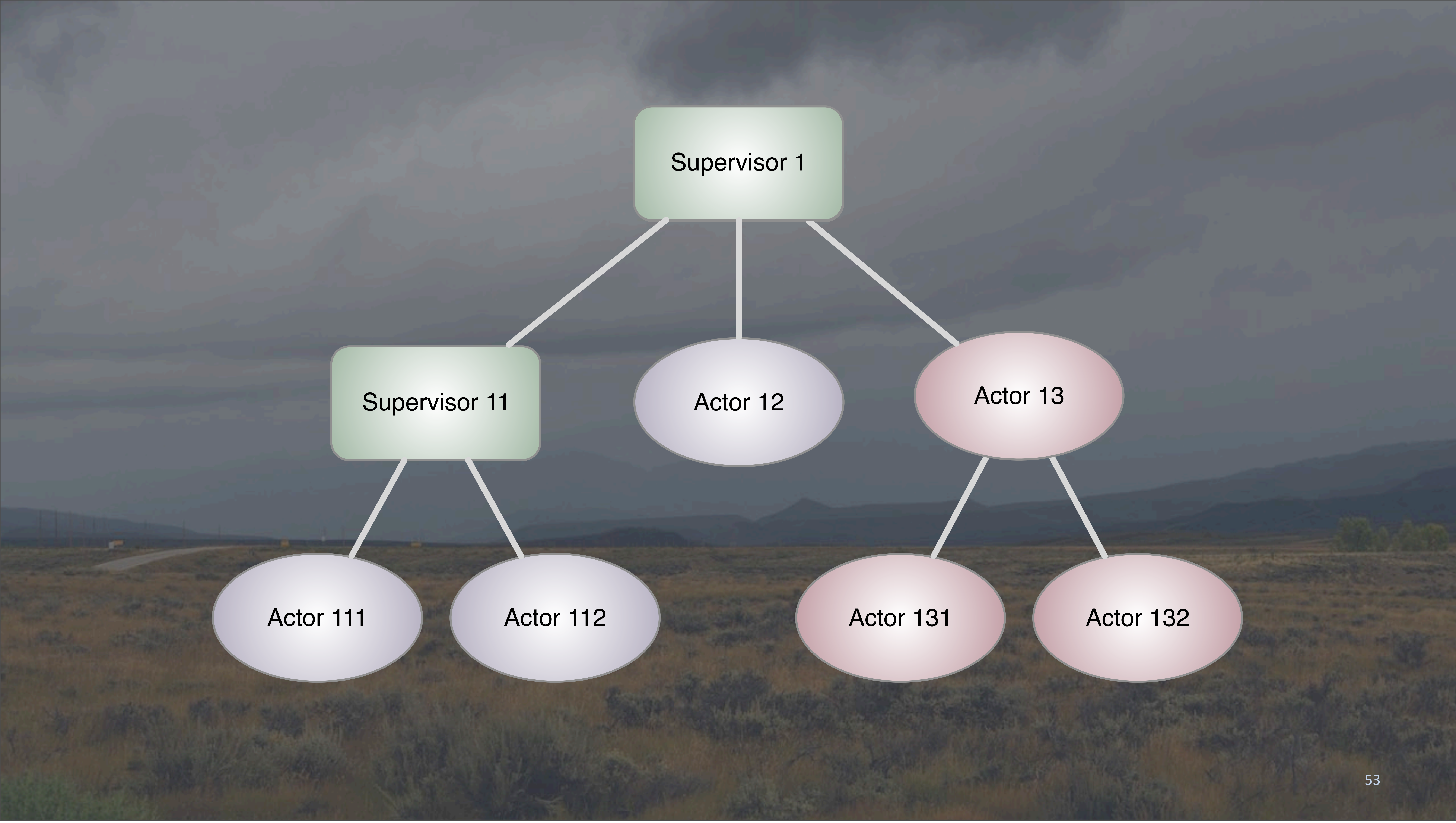
Tuesday, May 19, 15

An actor dies. This one has children, too.



Tuesday, May 19, 15

The supervisor tears down the tree of dependent actors, then...



Tuesday, May 19, 15

... it reconstructs it.

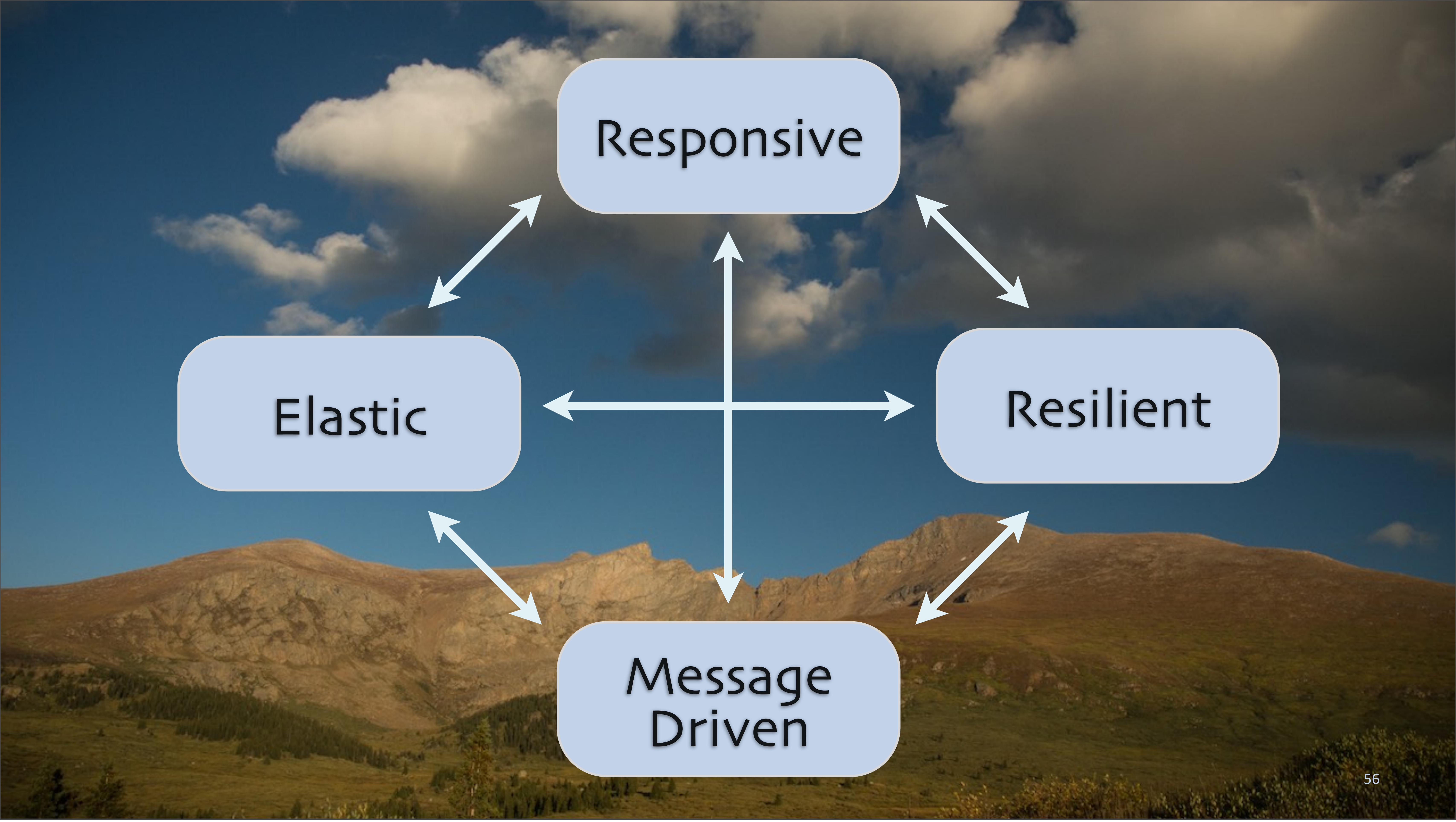
Tuesday, May 19, 15

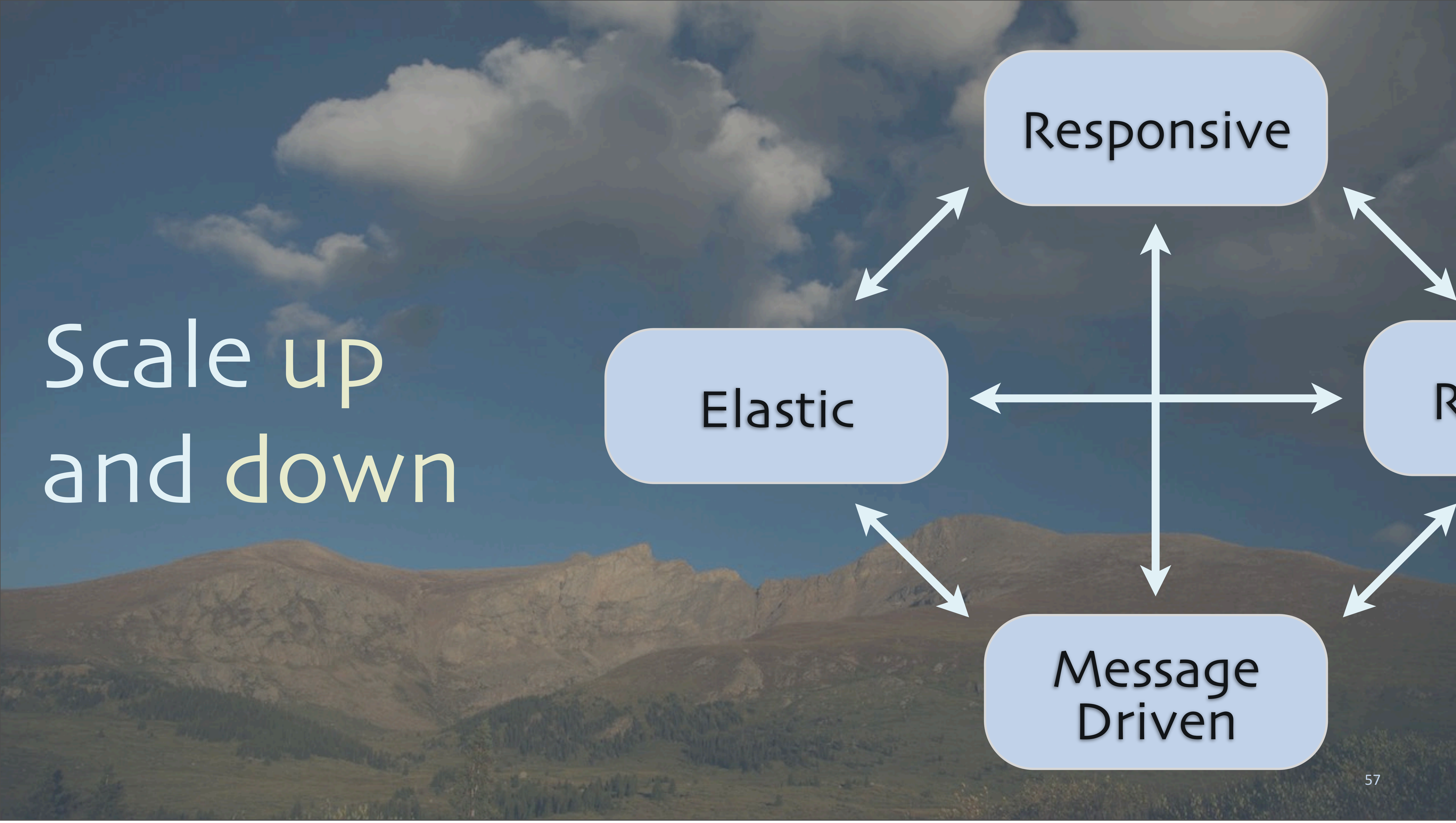
Very important at scale. Exception handling is too limited for large-scale recovery and mixing error handling with normal logic complicates code.

Not using Actors?
Consider Hystrix
from Netflix or similar...

https://github.com/Netflix/Hystrix

I believe every environment must solve this problem one way or another.


Responsive
Elastic
Resilient
Message Driven



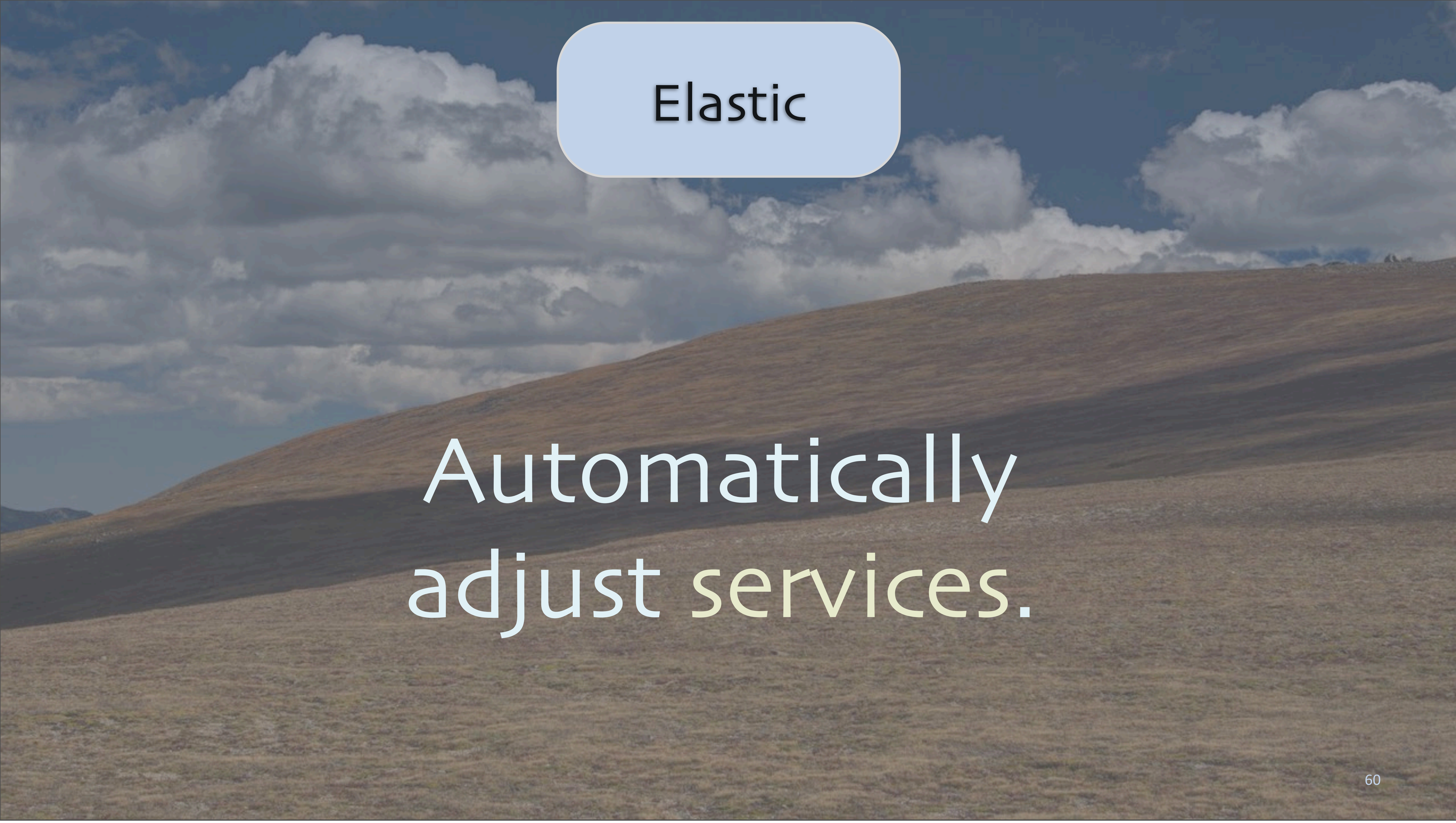
Tuesday, May 19, 15

As demand rises and falls, you must gracefully scale up to meet increasing demand and scale down to conserve resources.

Elastic

Tuesday, May 19, 15

Not as trivial as it might sound. Just how big is this spike going to be? When do I pull the trigger to grow or shrink resources? Machine learning is sometimes used to predict when to change based on past experience.



Tuesday, May 19, 15

Human intervention has to be minimal for this to really work.

Tuesday, May 19, 15

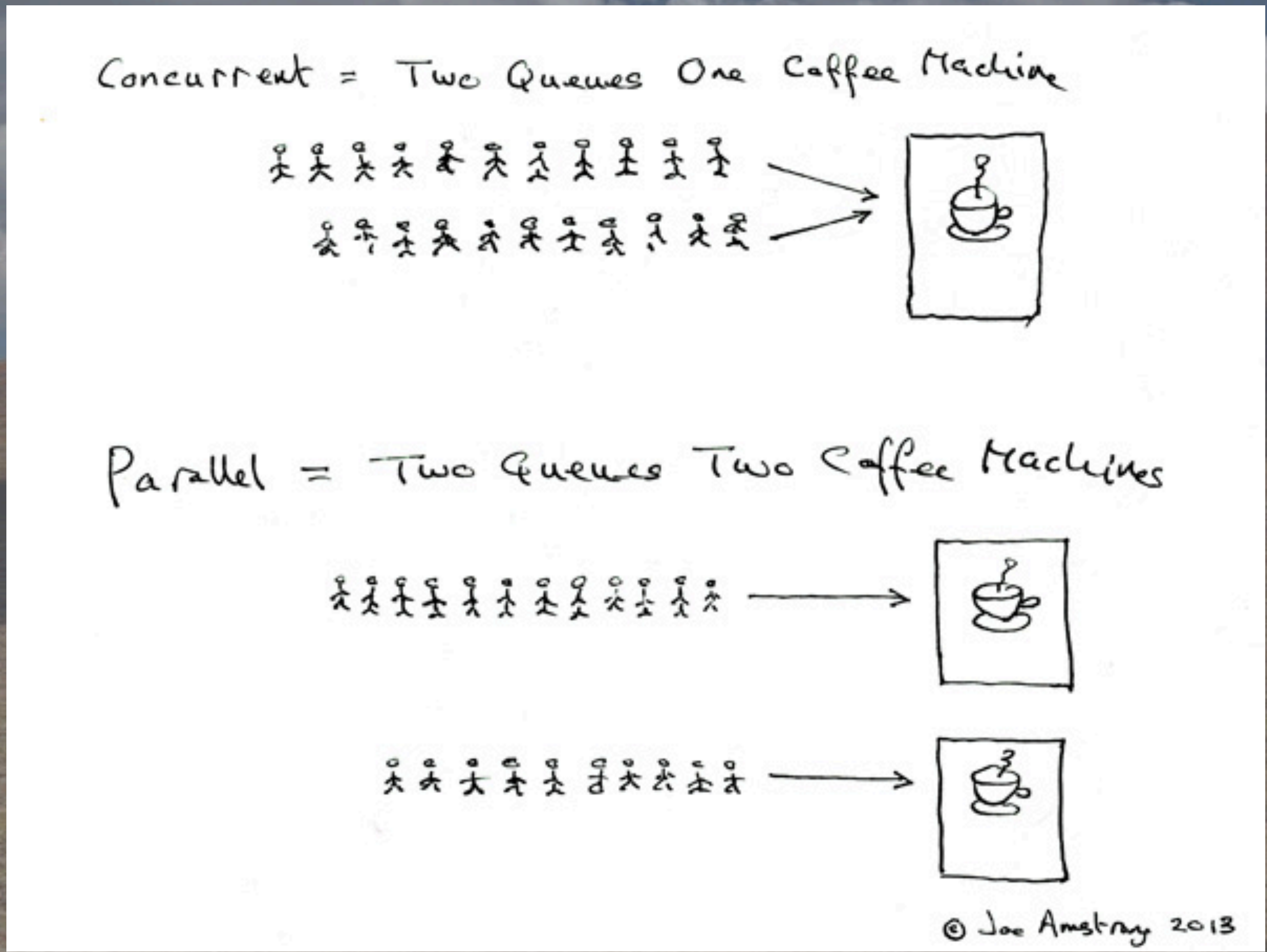
Typically you use redundant services again, across commodity (interchangeable) hardware.


Elastic
No bottlenecks
or contention points.
62

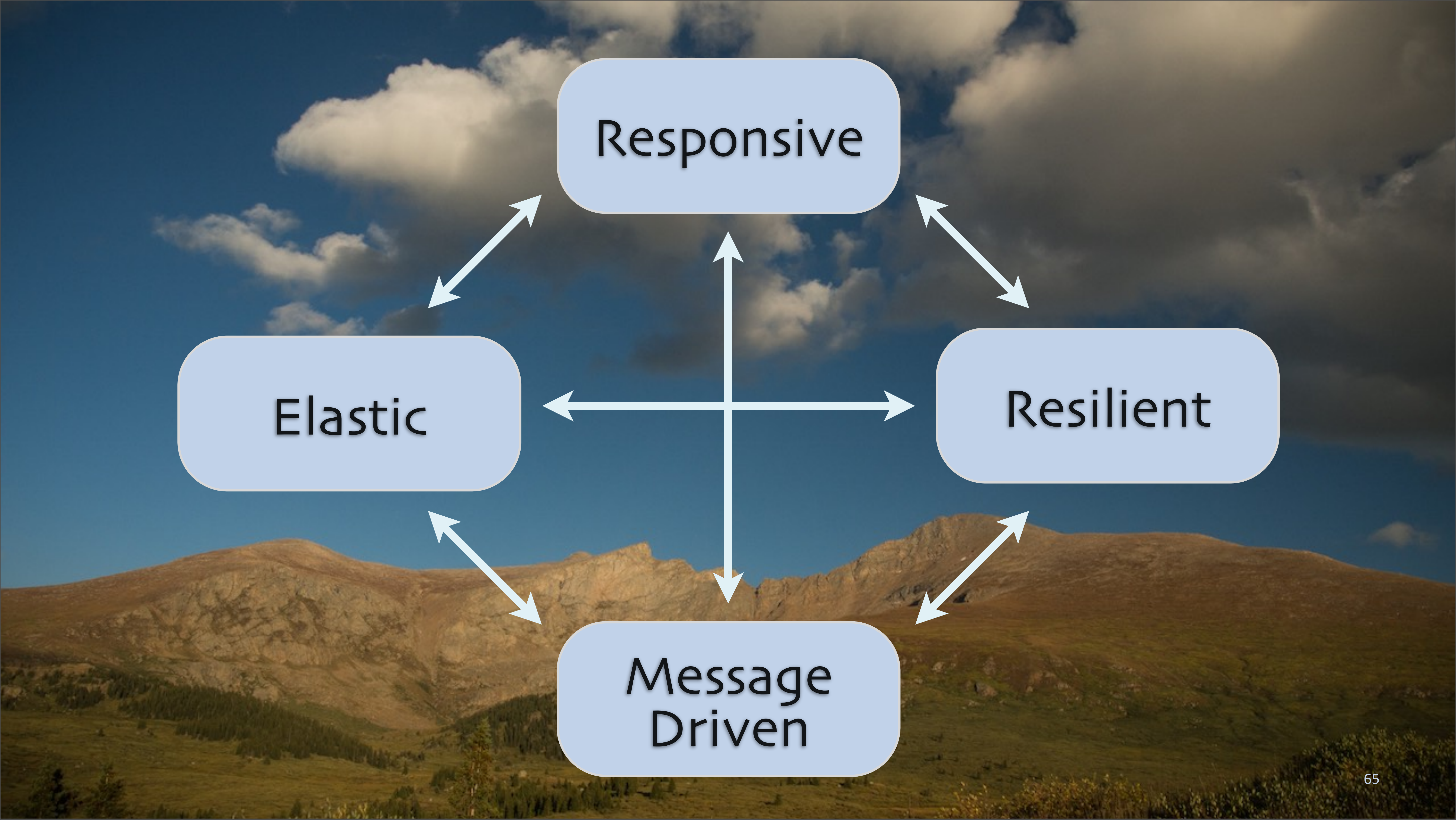
Tuesday, May 19, 15

So, harder if the nodes hold data!

Elastic



“Concurrent” vs. “parallel”.


Responsive
Elastic
Resilient
Message Driven

Tuesday, May 19, 15

To be responsive to the world around you, you must interact with it through messages.

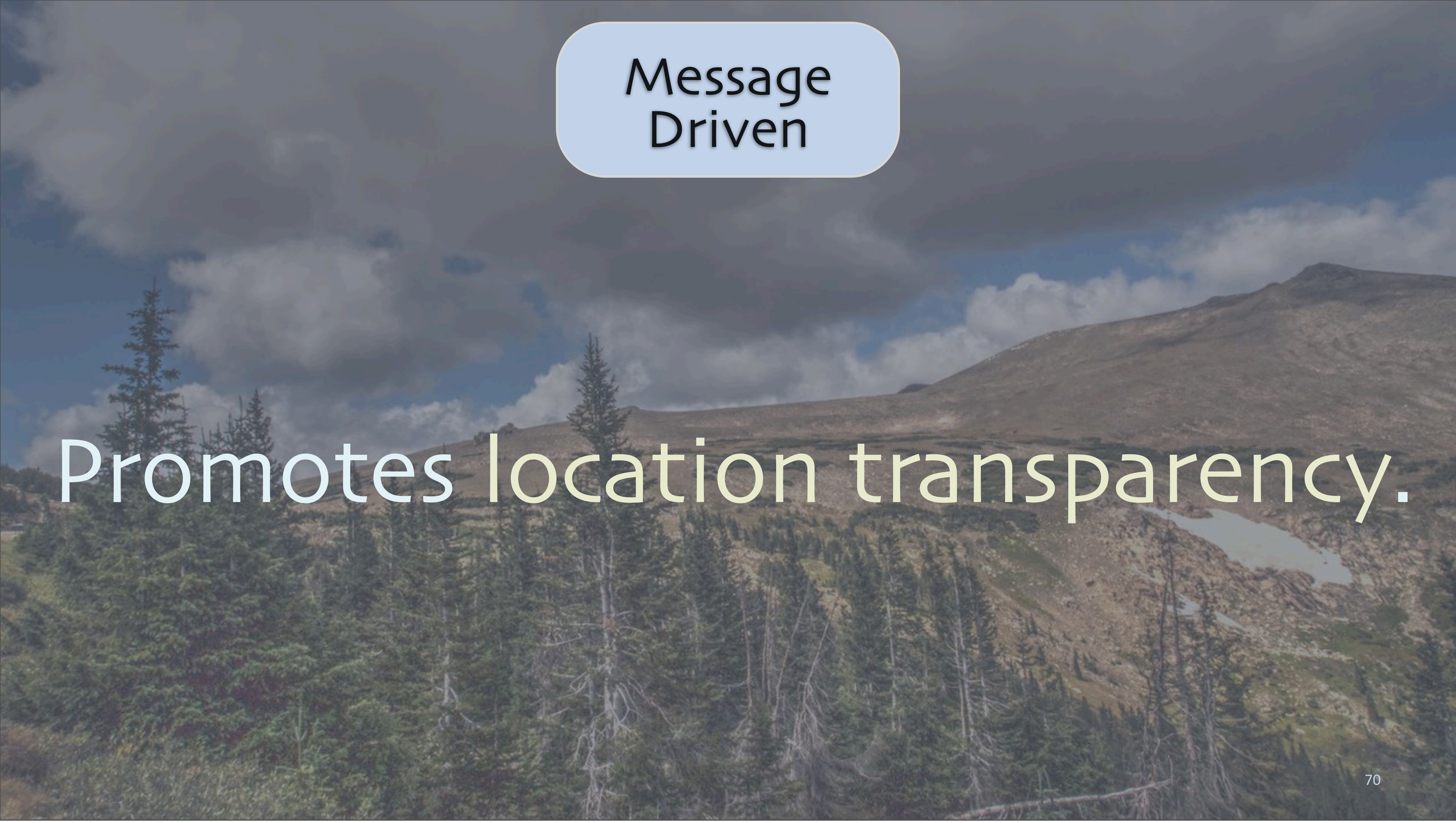
Message Driven

Tuesday, May 19, 15

It can’t be command and control. Blocking while waiting for a response fails to scale. (See Amdahl’s Law)

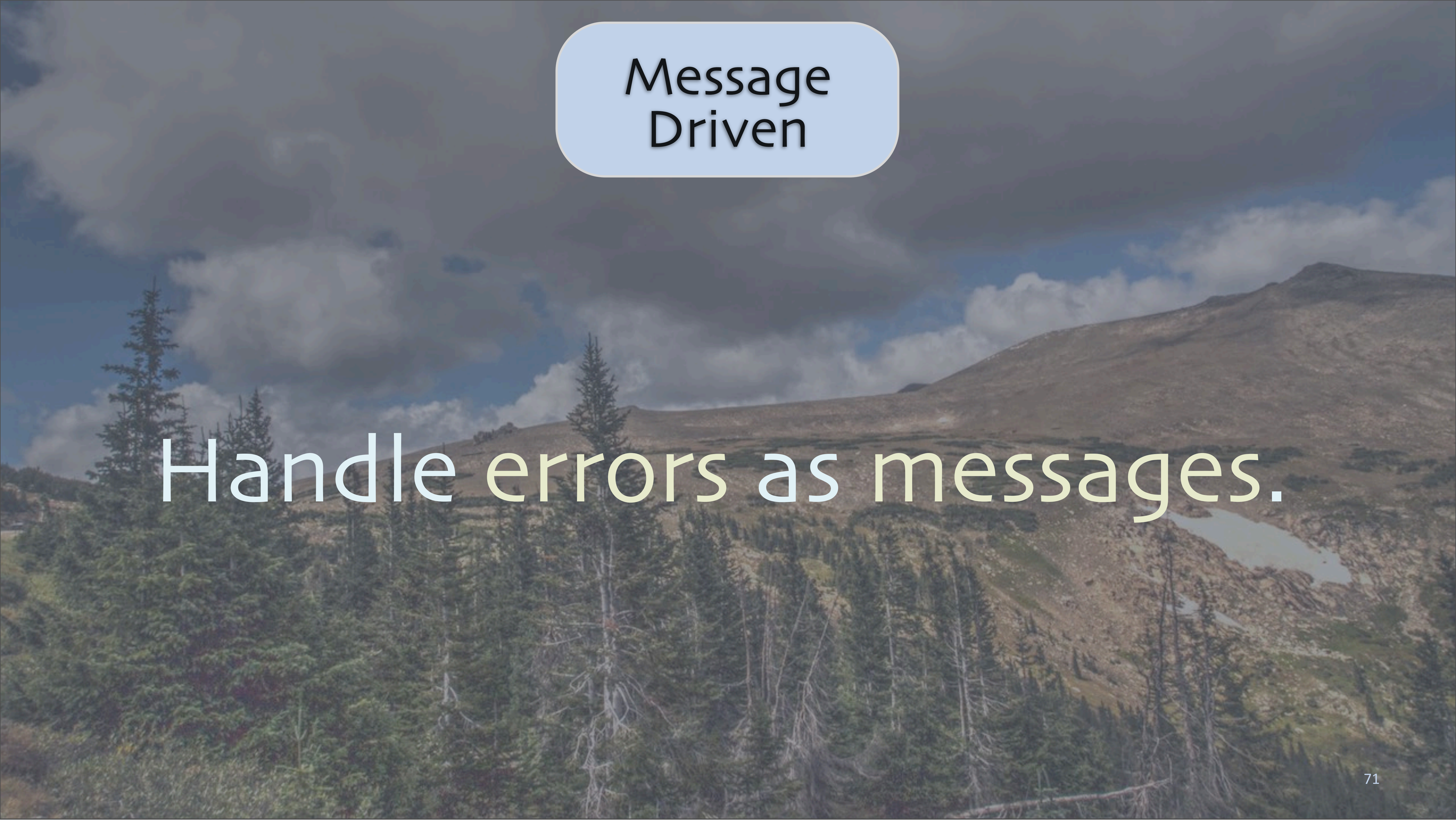
Tuesday, May 19, 15

Clear separation between components (whether or not the messages cross process boundaries), which encourages effective decomposition into focused services that are isolated from each other and loosely coupled.



Tuesday, May 19, 15

Source and receiver can change, so services can be migrated to adapt to changing load dynamics.



Tuesday, May 19, 15

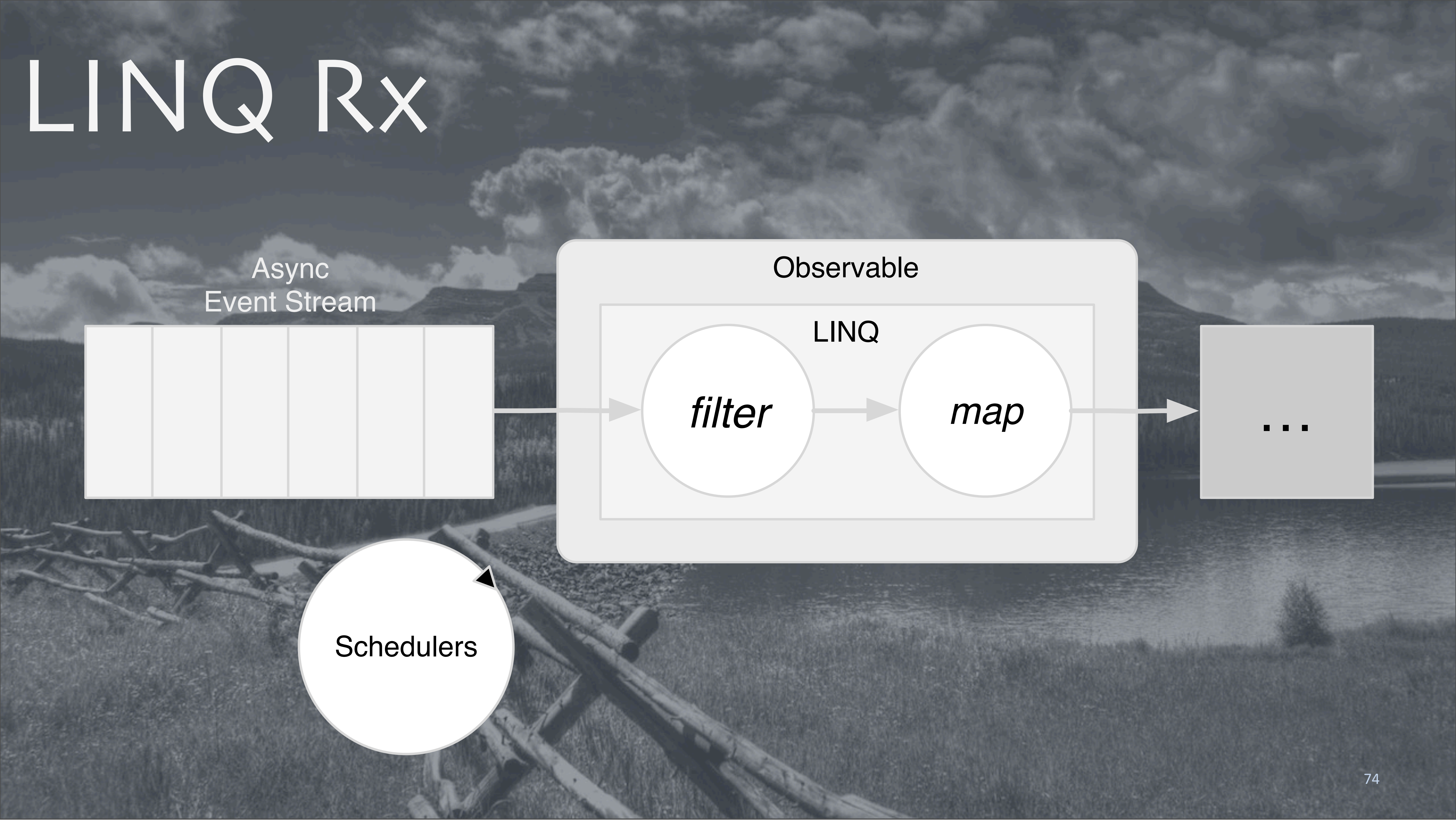
Also, you can use the same message infrastructure to communicate error scenarios as well as normal processing.

Tuesday, May 19, 15

Think of the messages as forming a stream. If a common implementation infrastructure is used, it’s possible to monitor and manage traffic flow. Back pressure is the idea of communication between sender and receiver to control the rate of flow. We’ll return to it.

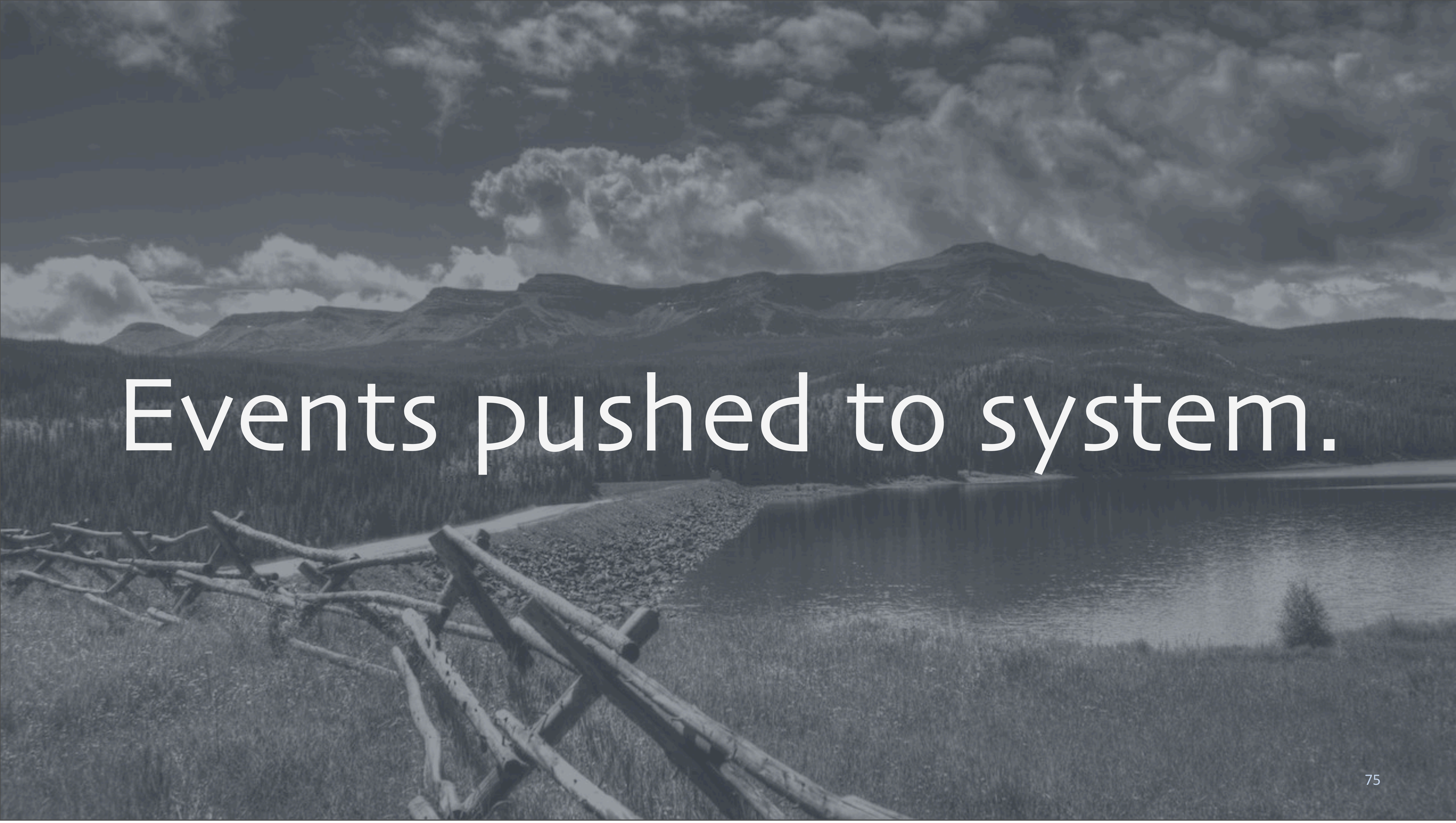
Tuesday, May 19, 15

Rx was pioneered by Erik Meijer for .NET. Now ported to several languages, including RxJava (Netflix) and React (JS - Facebook).



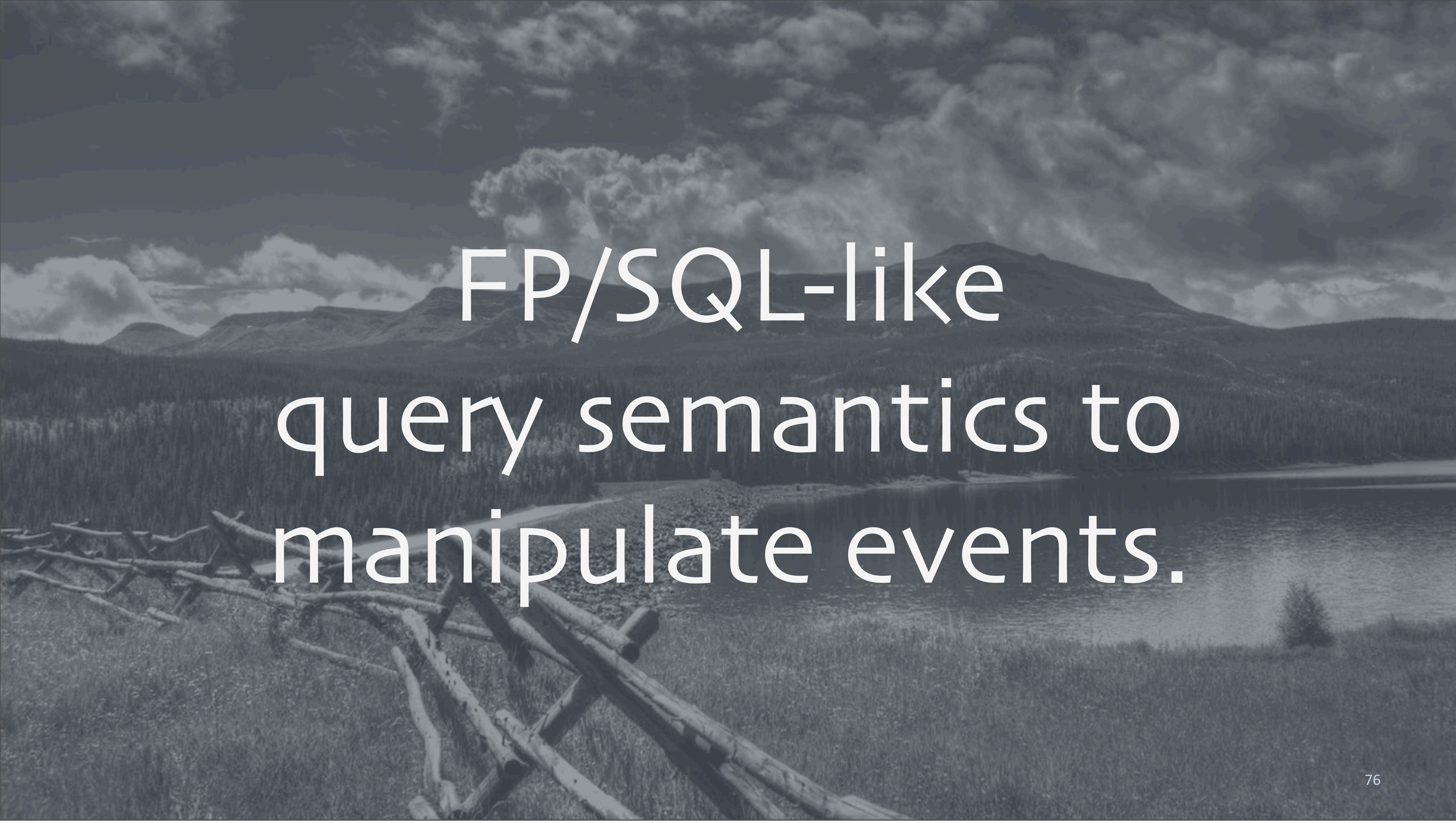
Tuesday, May 19, 15

Events are observed (an extension of the observer pattern). Operations like filtering and mapping are provided to work with the stream through LINQ (Language Integrated Query), which uses SQL-like expressions. The Schedulers are used to trigger processing.



Tuesday, May 19, 15

It’s essentially a push model.


FP/SQL-like
query semantics to
manipulate events.
76

How: Reactive Tools

We mentioned a few already, let’s fill in some details. This won’t be an exhaustive list.
Hat tip to Jamie Allen at Typesafe for some of these ideas.

Tuesday, May 19, 15

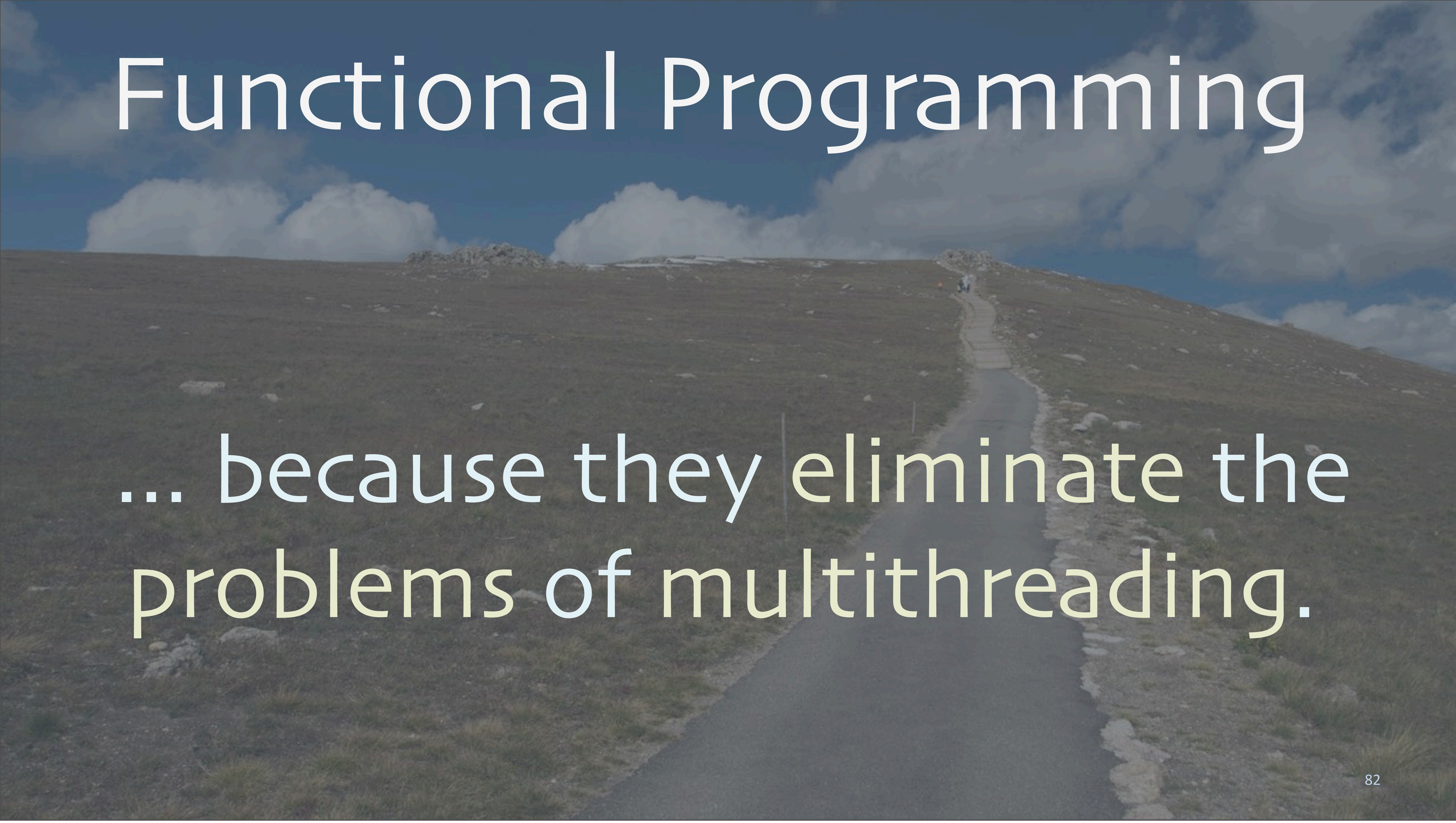
We mentioned a few already, let's fill in some details. This won't be an exhaustive list.

Tuesday, May 19, 15

CSP - Communicating Sequential Processes.

Functional Programming

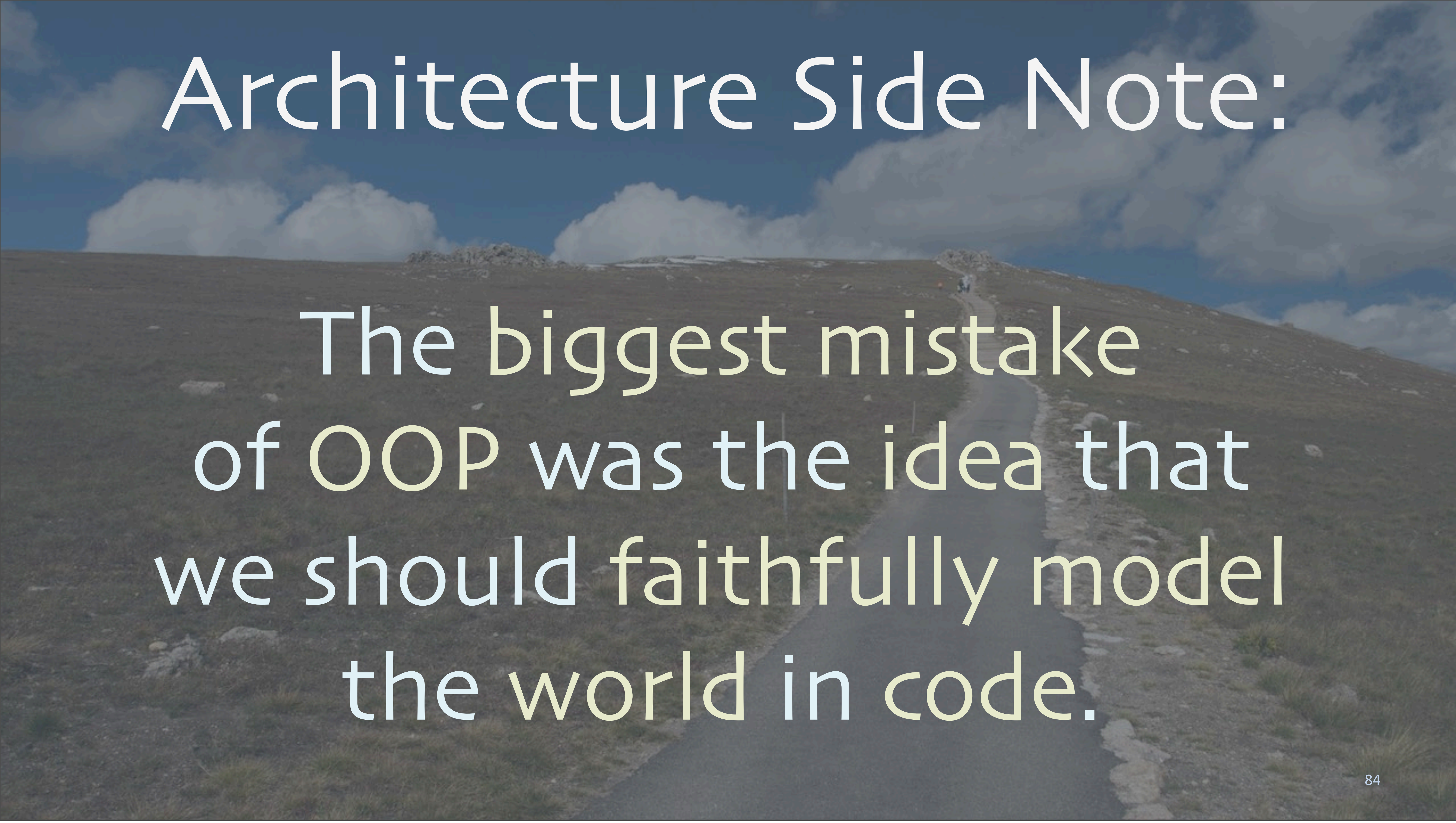

Functional Programming
Prefer immutable values and side-effect free functions...
81



Tuesday, May 19, 15

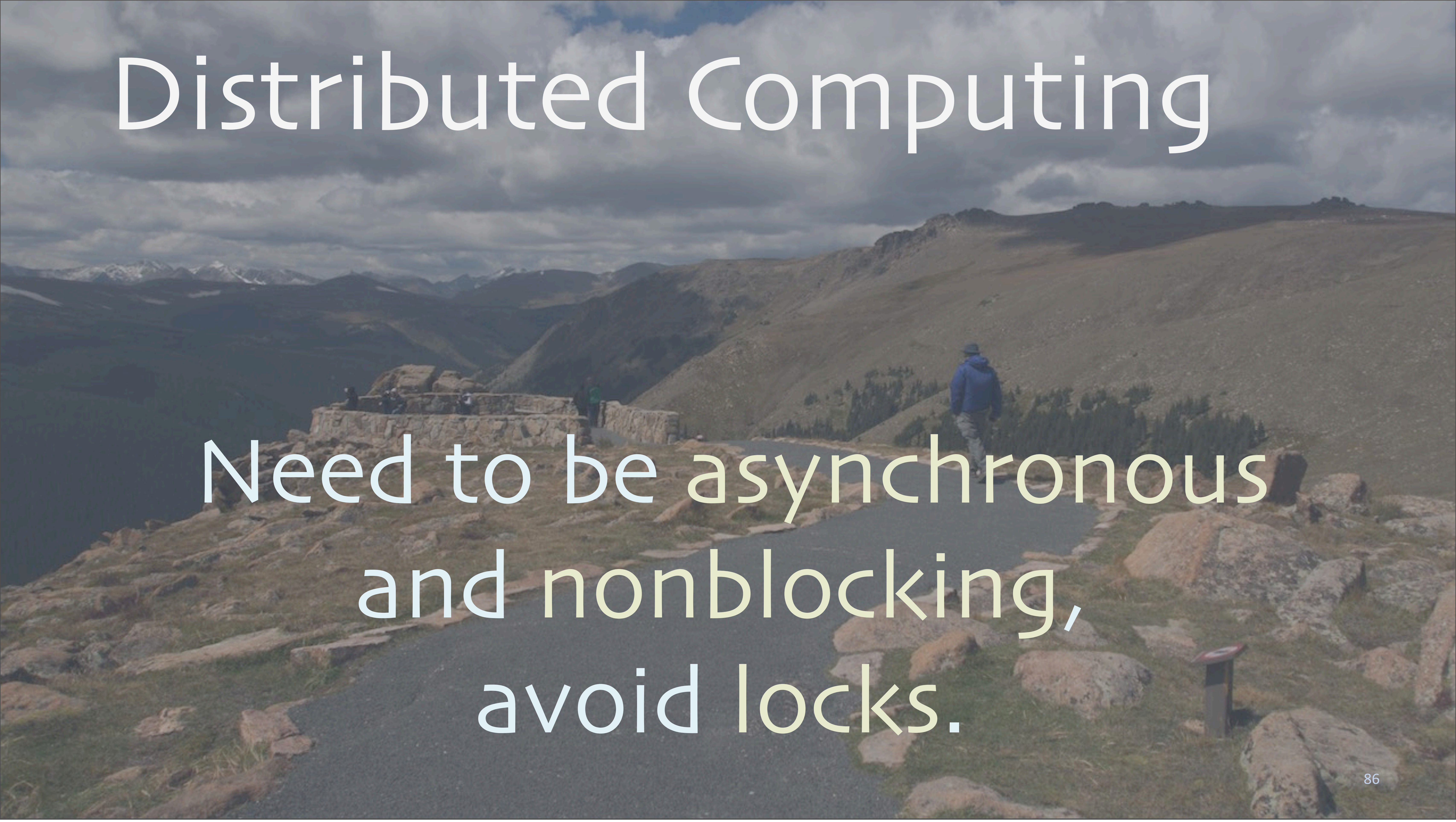
Why, because all the problems are caused by attempting to coordinate access to shared,mutable state. If the state is no longer mutable, then it’s trivial to share. There are many other advantages of FP.

This is Scala’s view, that objects are useful as module constructs, but the code inside should be functional.



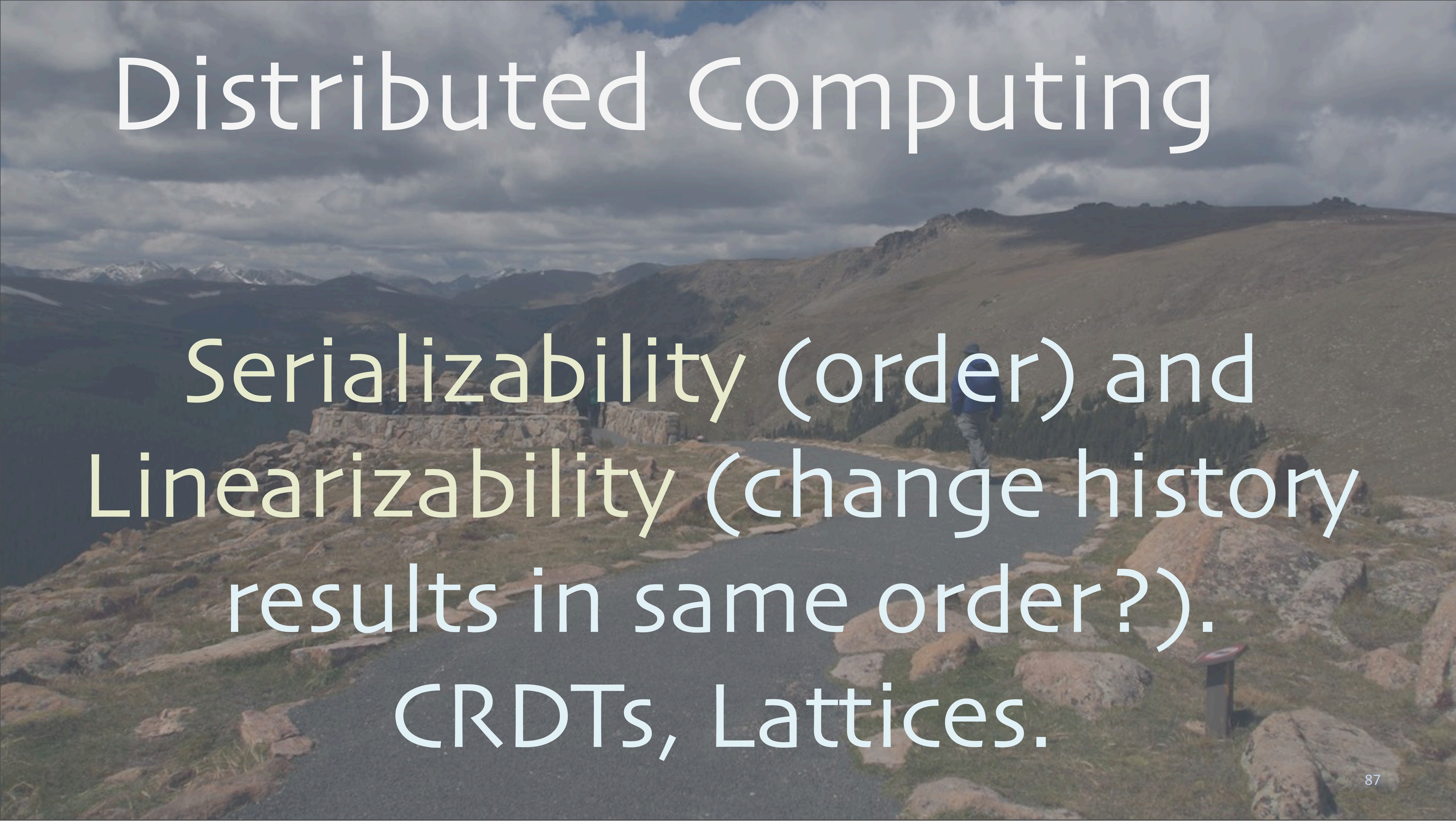
Controversial, but I believe much of our code bloat and inflexibility is actually caused by this mistaken belief. Example: Does a payroll calculator need the concepts of Pay, Deductions, etc.? Or should we just stream numbers through math logic?

Distributed Computing



Tuesday, May 19, 15

Messaging passing should be asynchronous. Any expensive calculation should be executed async, too, so main threads are not blocked. There are many lock-free algorithms and datastructures now. Locks kill scalability and they are hard to program correctly.

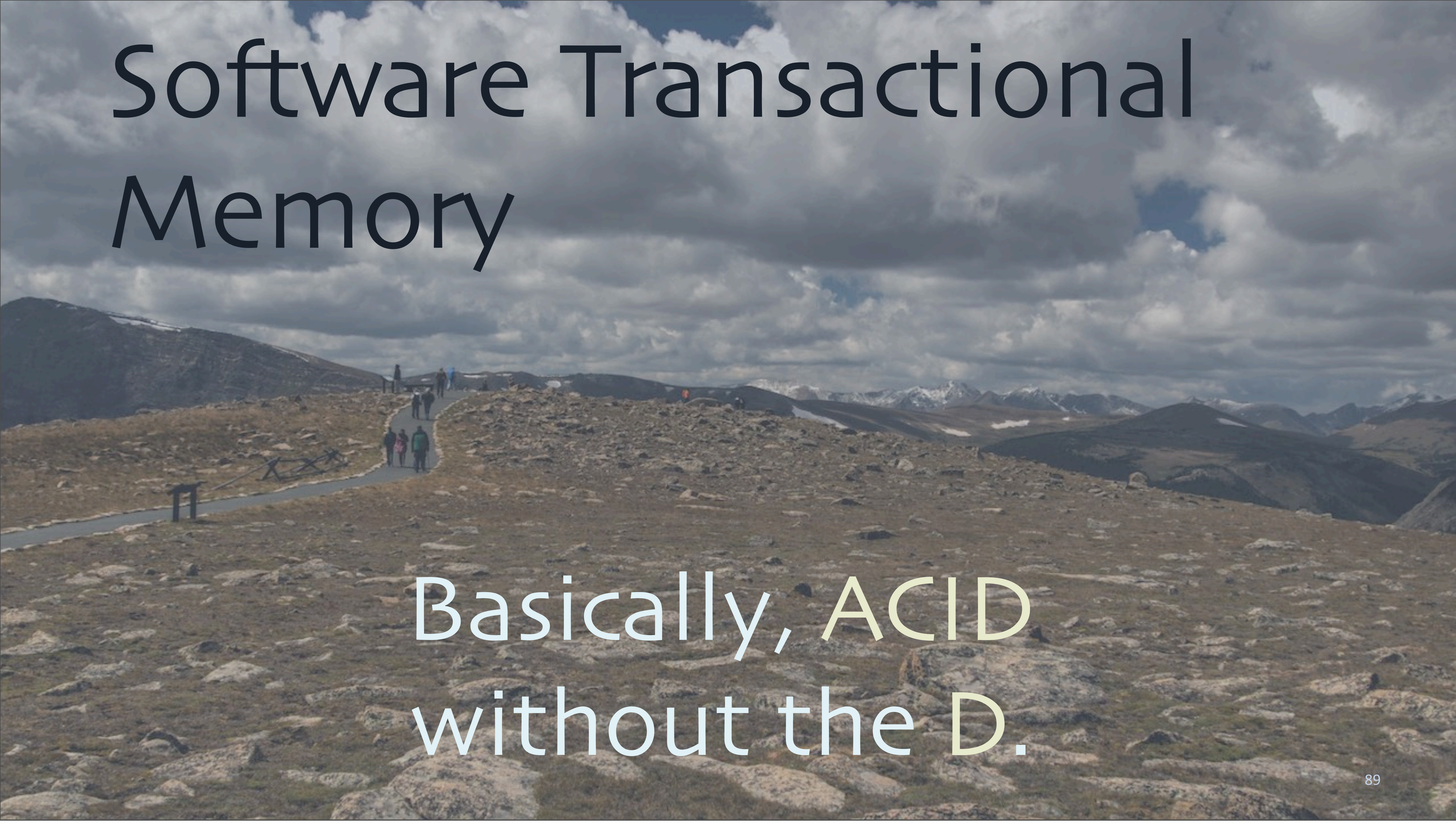


CRDTs - Commutative Replicated Data Types (http://pagesperso-systeme.lip6.fr/Marc.Shapiro/papers/RR-6956.pdf)
Lattices are more general concept applied here.

Software Transactional Memory

Popularized first in Hardware, then in Software by Haskell. Now used in persistent datastructures in many languages. Great description of STM by Simon Peyton-Jones, from the O’Reilly Book Beautiful Code, http://research.microsoft.com/en-us/um/people/simonpj/papers/stm/#beautiful

Software Transactional Memory

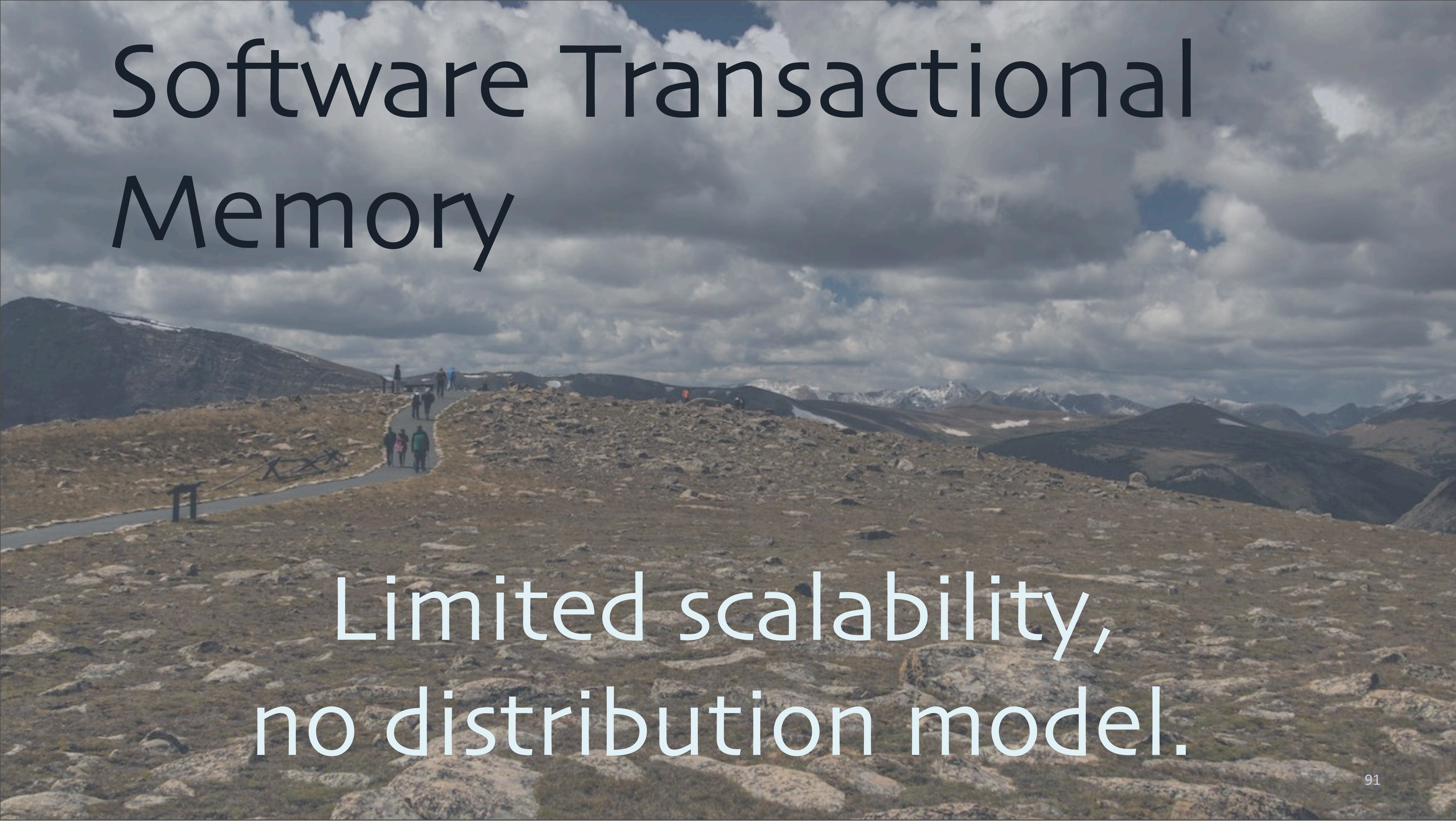


Basically, ACID without the D.

Software Transactional Memory

Principled local state mutation through transactions.

Software Transactional Memory



Limited scalability,
no distribution model.

Tuesday, May 19, 15

A very powerful tool for avoiding local locks and unprincipled mutation, but not a tool that scales to the global challenges we’re discussing here.

Event Loops

Tuesday, May 19, 15

The standard technique for message/event driven programming. Usually pull based, for something that loops continuously pulling events off a queue, or push based with callbacks.

Tuesday, May 19, 15

Consumes a thread, which can limit scalability. The event handler must not take too long or the queue can either grow to exhaust available memory (unbounded) or drop events (bounded).

Tuesday, May 19, 15

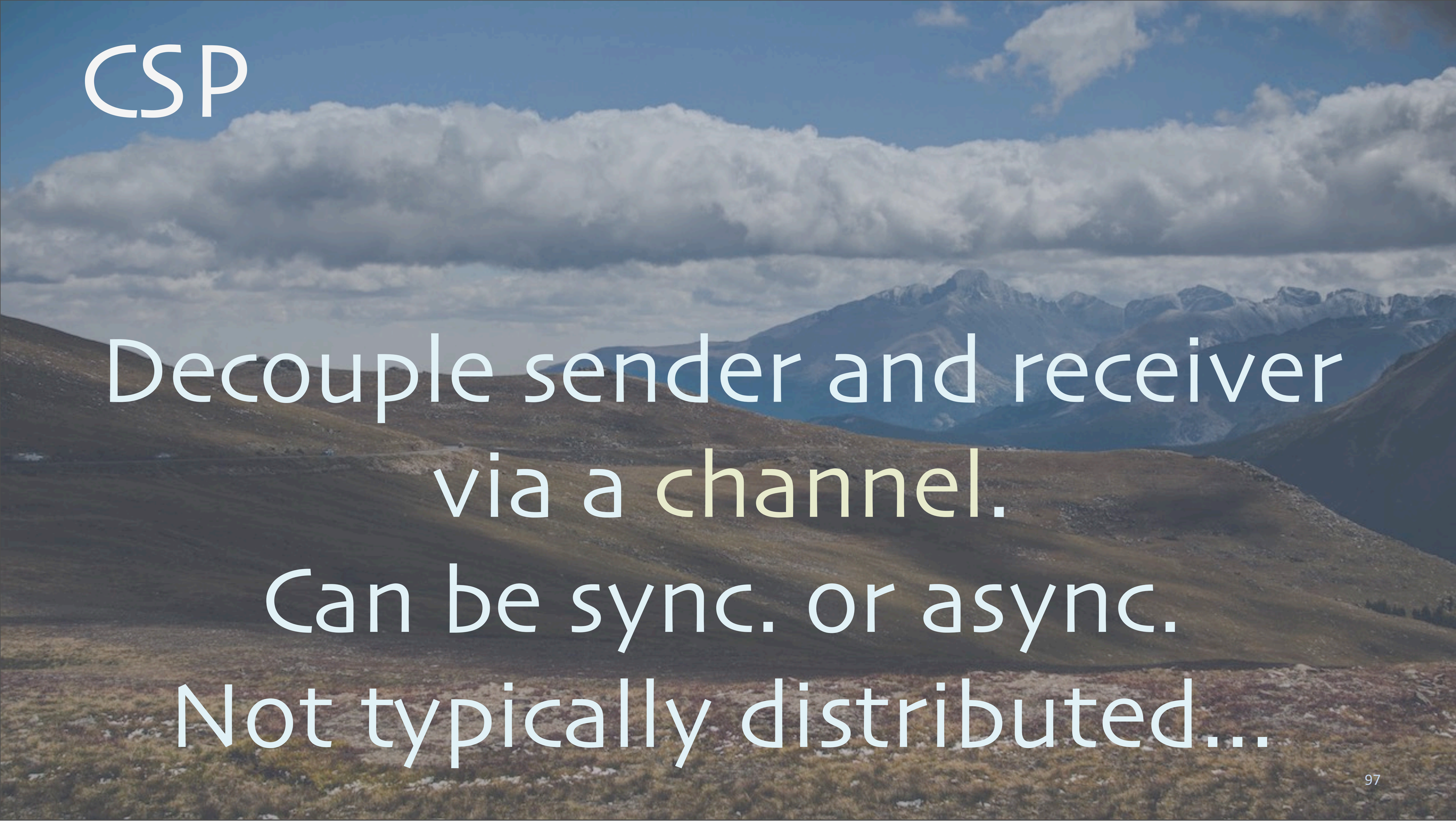
Can use threads more efficiently, but callback hell is sometimes a problem.

Tuesday, May 19, 15

Many of these systems don’t provide facilities for distribution or error recovery.

Tuesday, May 19, 15

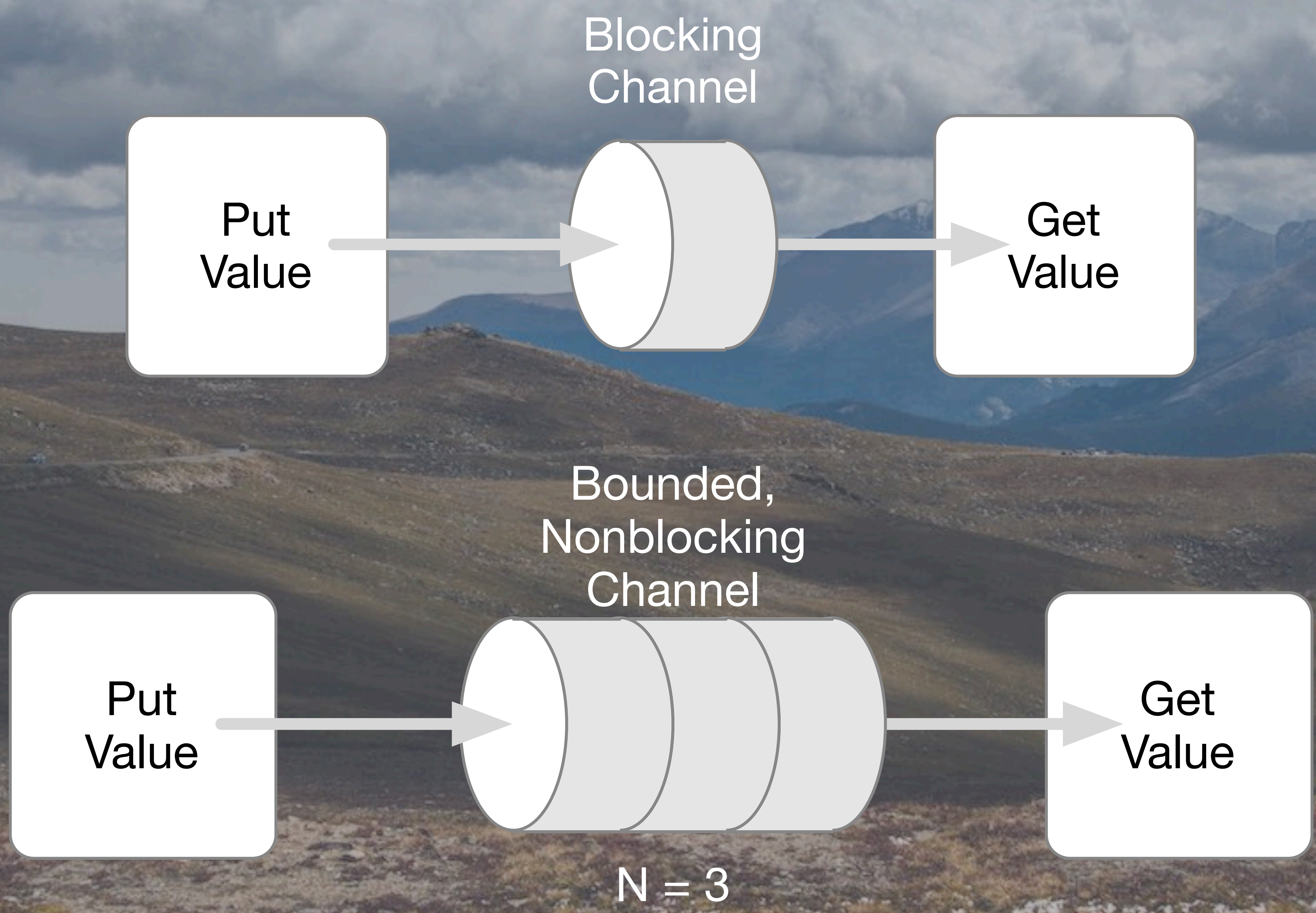
Communicating Sequential Processes - The first mathematical model of distributed computing. It has evolved somewhat and it’s still popular in Clojure and Go, for example.



Tuesday, May 19, 15

Great abstraction for coordinating exchange of data, with a level of abstraction, the channel. Not really a scalable distributed system in the general sense.

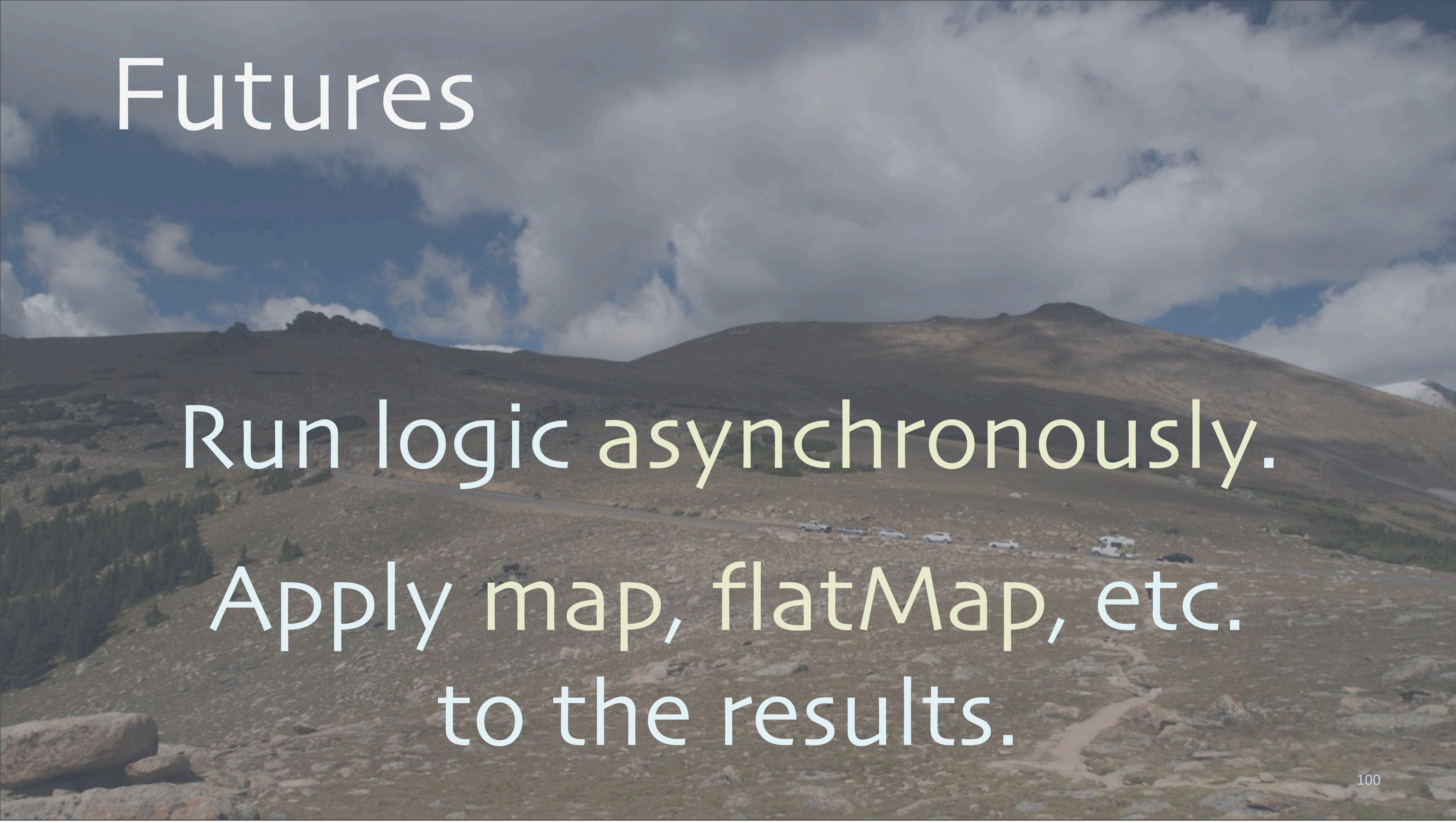
CSP



Tuesday, May 19, 15

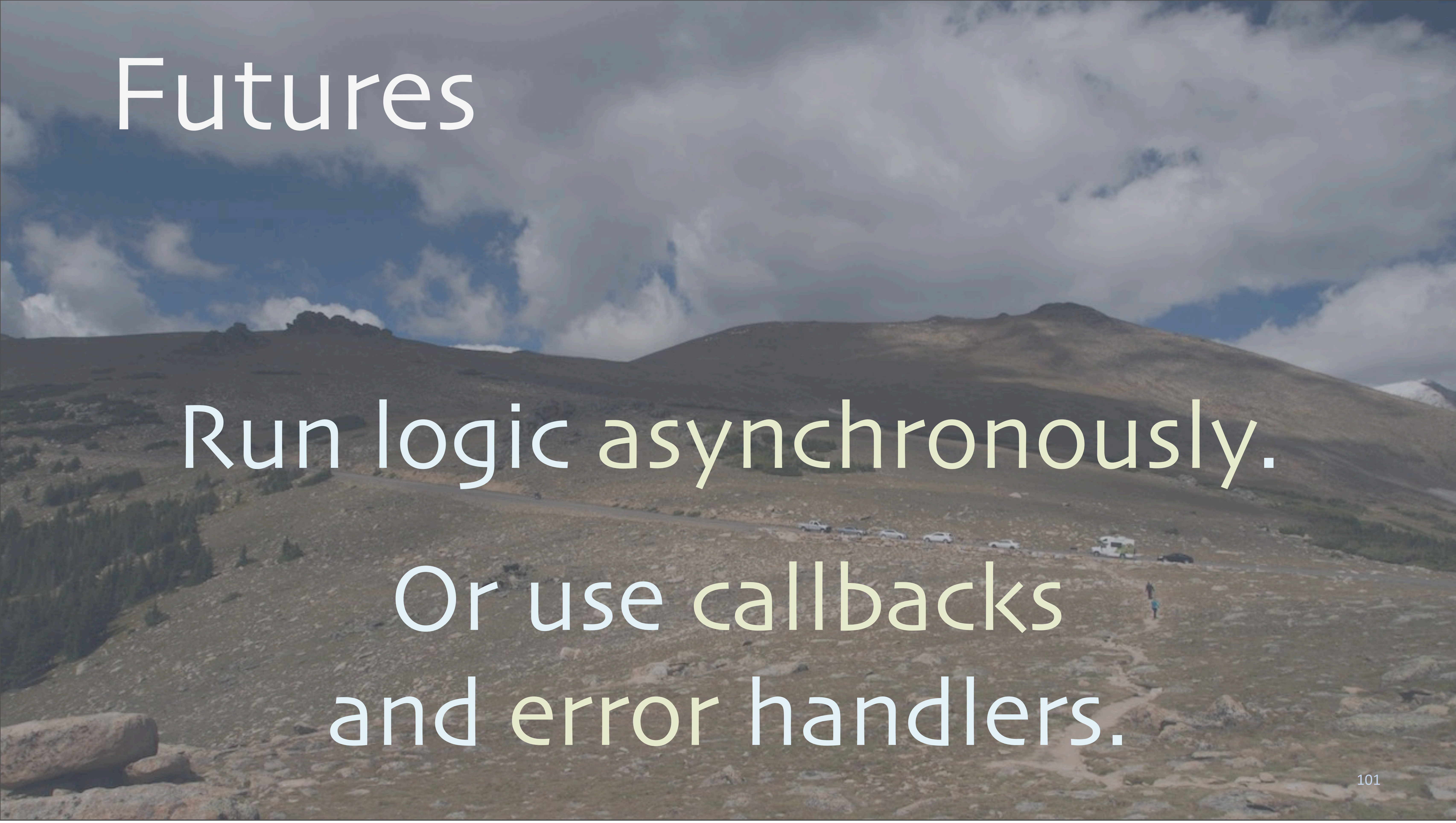
Schematic view of simple CSP interactions. If the channel queue has one slot, then it’s blocking; the “putter” wait for a “getter” to be on the other side. If there are >1 slots, the putter won’t block unless all the slots are full. See my talk on error handling in reactive systems where I discuss CSP in more detail. (I’ll discuss CSP vs. Actors in more depth in my other talk.)

Fill more or less the same niche as CSP. That is, most Futures and CSP systems cover the same scope of concurrency control, which is somewhat fine-grained as opposed to strategic.



Tuesday, May 19, 15

Like using the UNIX shell to fire a process in the background, but you either define callbacks to handle the success or failure (a more procedure-oriented approach) or use functional operations like map, etc. to process the results on success.

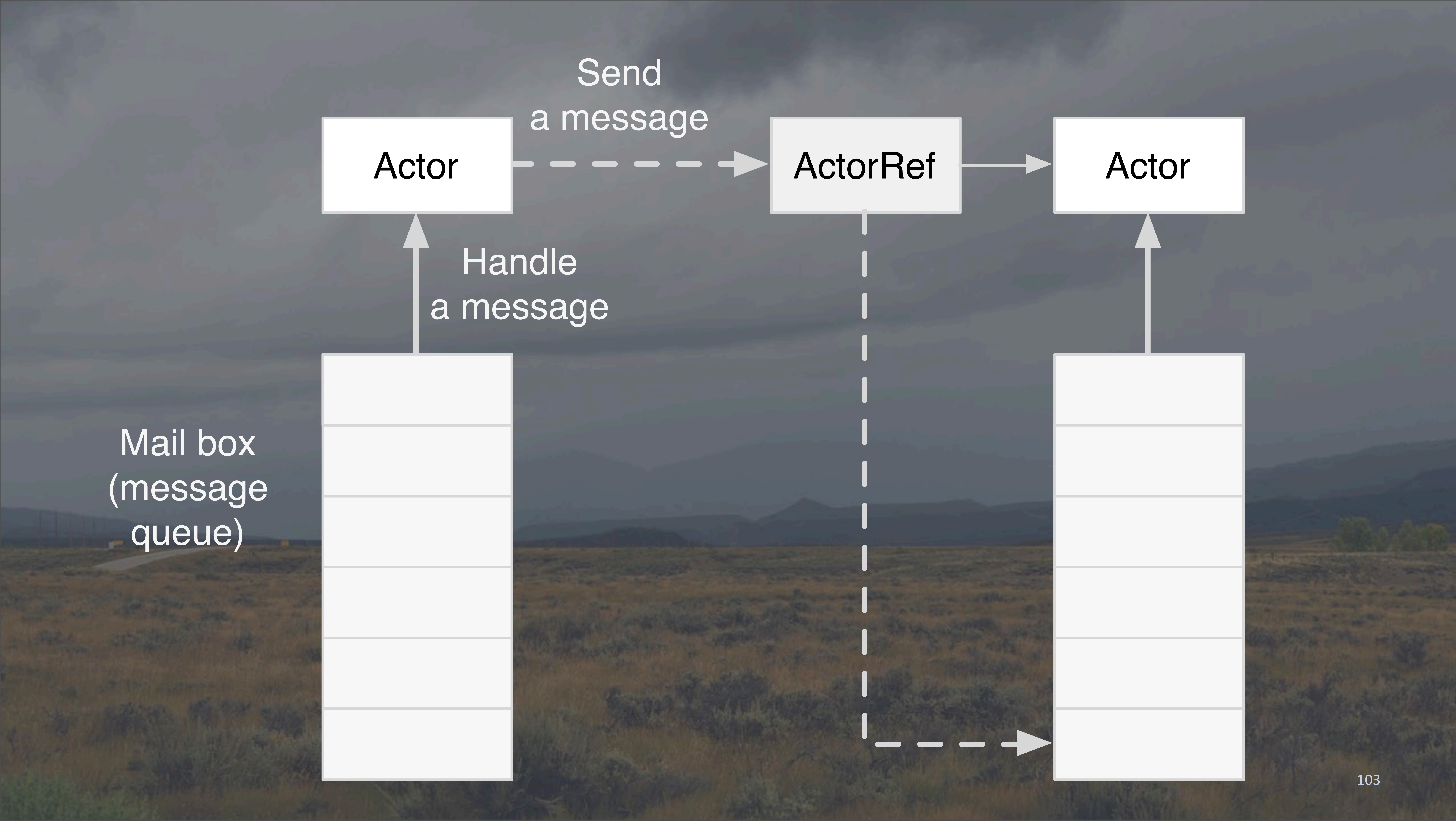


Tuesday, May 19, 15

Like using the UNIX shell to fire a process in the background, but you either define callbacks to handle the success or failure (a more procedure-oriented approach) or use functional operations like map, etc. to process the results on success.

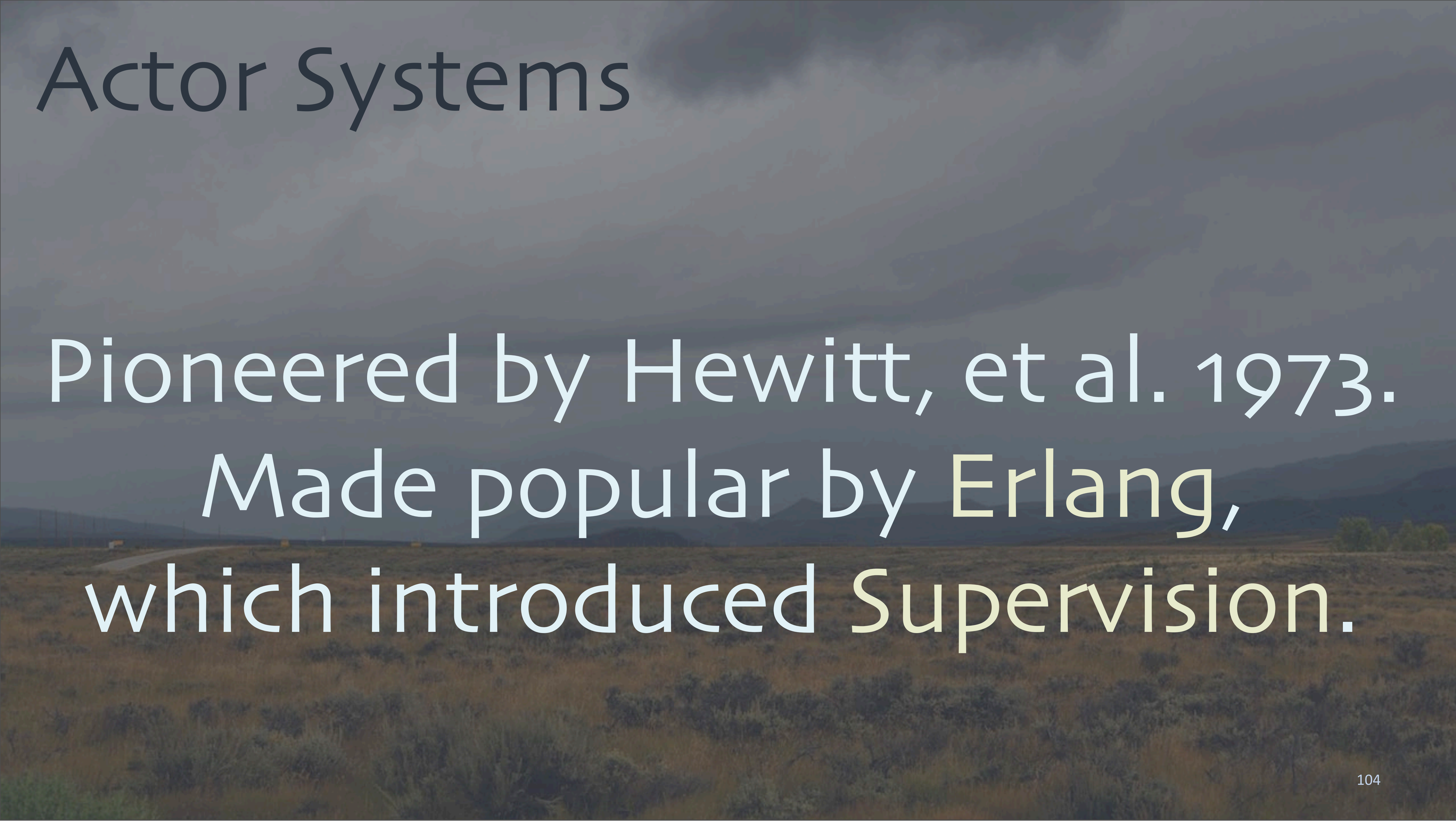
Tuesday, May 19, 15

We briefly visited this before.
Rather than attempt to recover from errors inside the domain logic (e.g., elaborate exception handling), allow services to fail, but with failure detection and reconstruction of those services, plus failover to other replicas.



Tuesday, May 19, 15

Actors are similar to objects in Smalltalk and similar systems; autonomous agents with defined boundaries that communicate through message passing. Actors, though process each message in a threadsafe way, so they are great for concurrency. (This diagram illustrates the Akka implementation – http://akka.io)

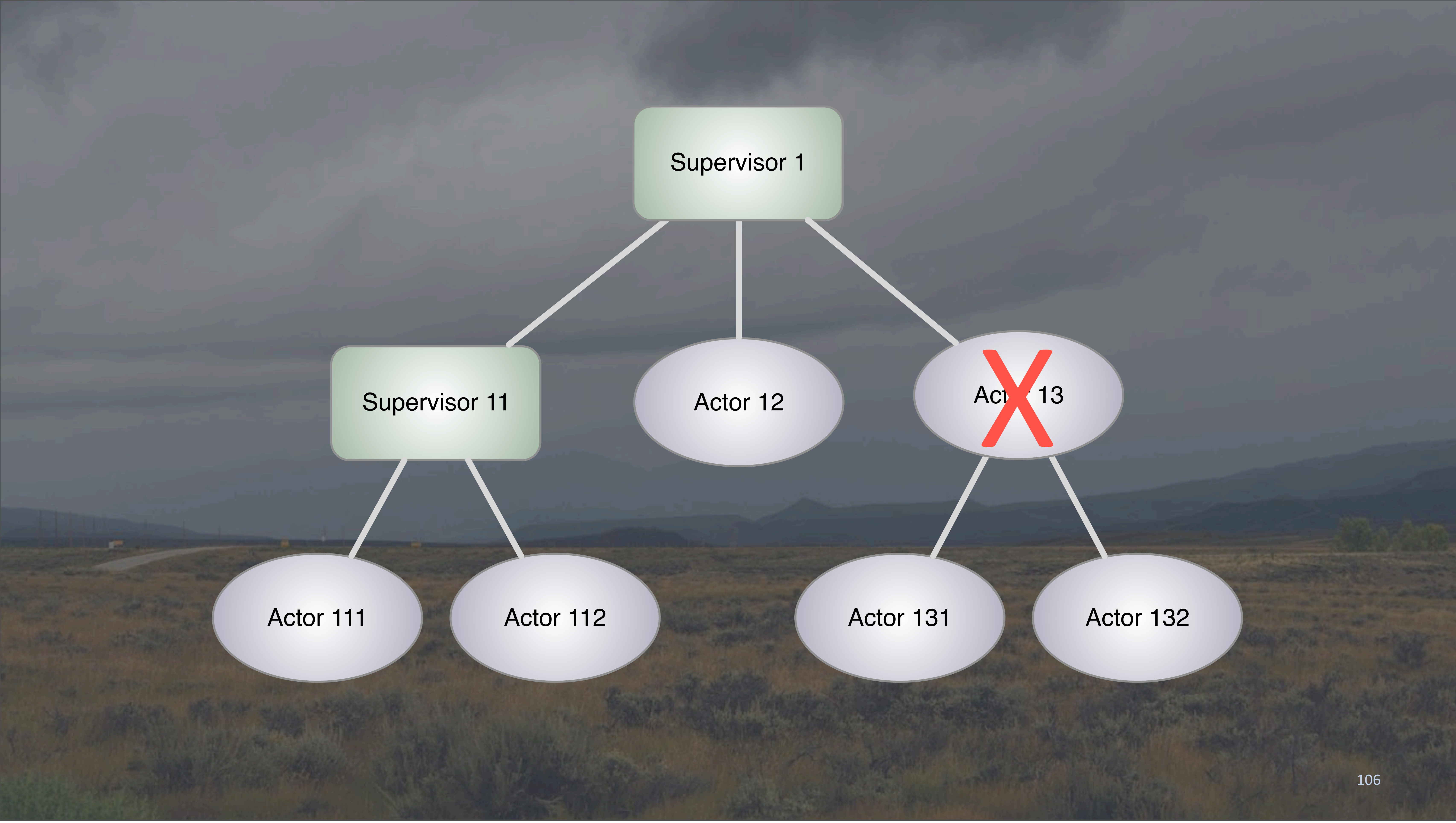


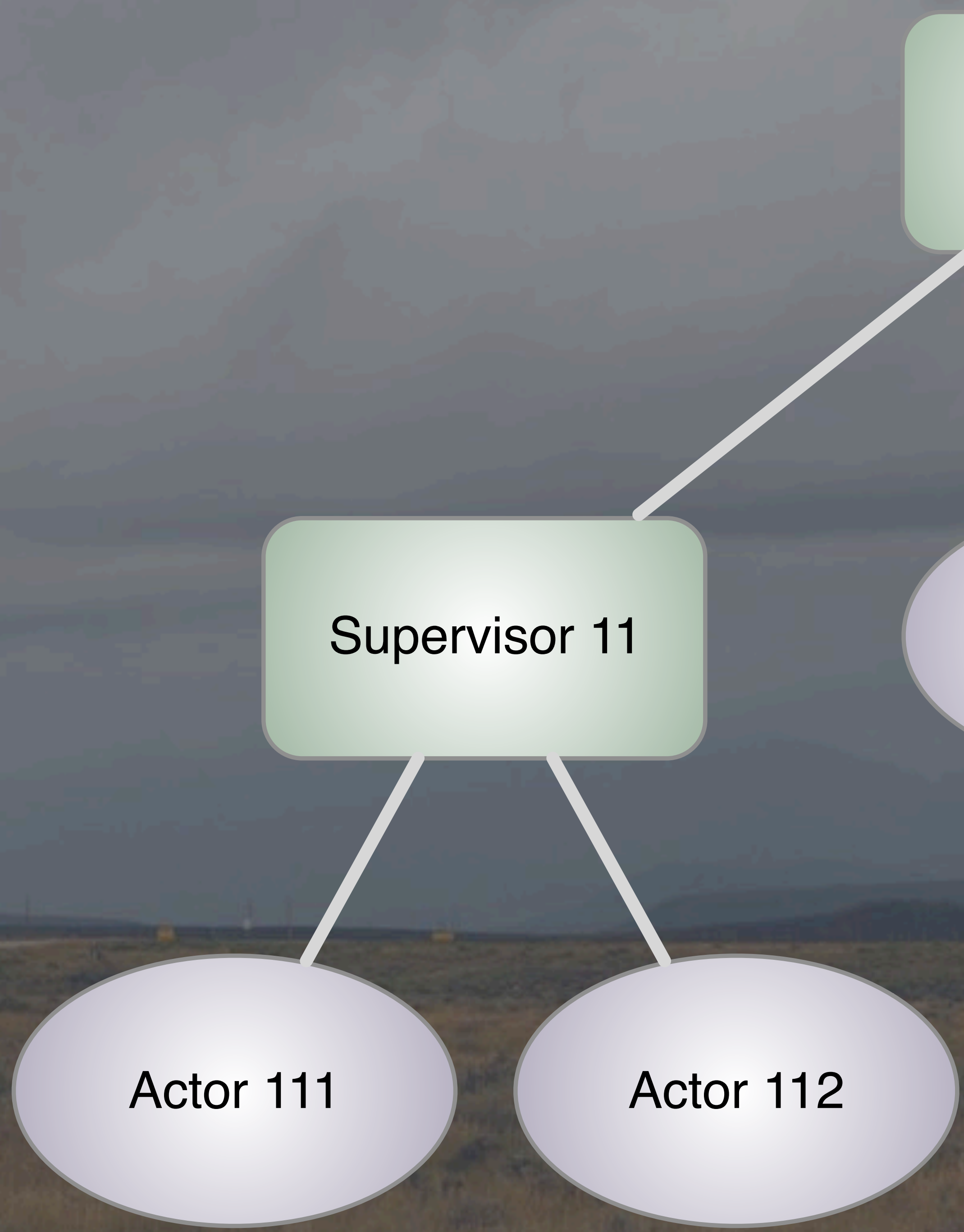
Tuesday, May 19, 15

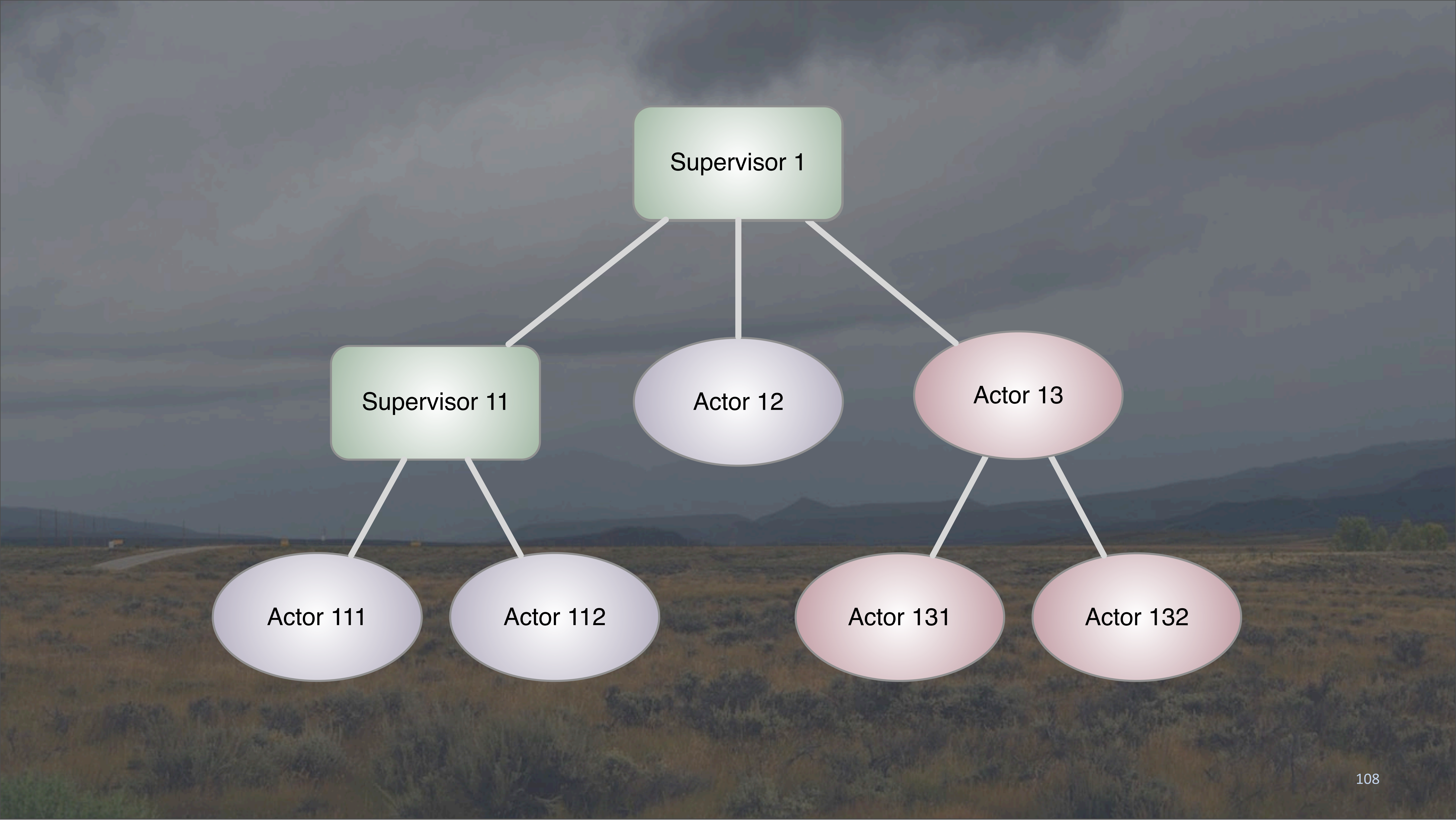
Erlang is a simple language with actor semantics baked in. It has been used to create extremely reliable telecom switches, databases (e.g., Riak), and other services (e.g., GitHub).

Tuesday, May 19, 15

Erlang is a simple language with actor semantics baked in. It has been used to create extremely reliable telecom switches, databases (e.g., Riak), and other services (e.g., GitHub).


Supervisor 1
Supervisor 11
Actor 12
Act 13
Actor 111
Actor 112
Actor 131
Actor 132


Supervisor 1
Supervisor 11
Actor 12
Actor 111
Actor 112


Supervisor 1
Supervisor 11
Actor 12
Actor 13
Actor 111
Actor 112
Actor 131
Actor 132

Tuesday, May 19, 15

Again, I'll discuss this in some more depth in my other talk.


Clean separation
of normal processing
from recovery.

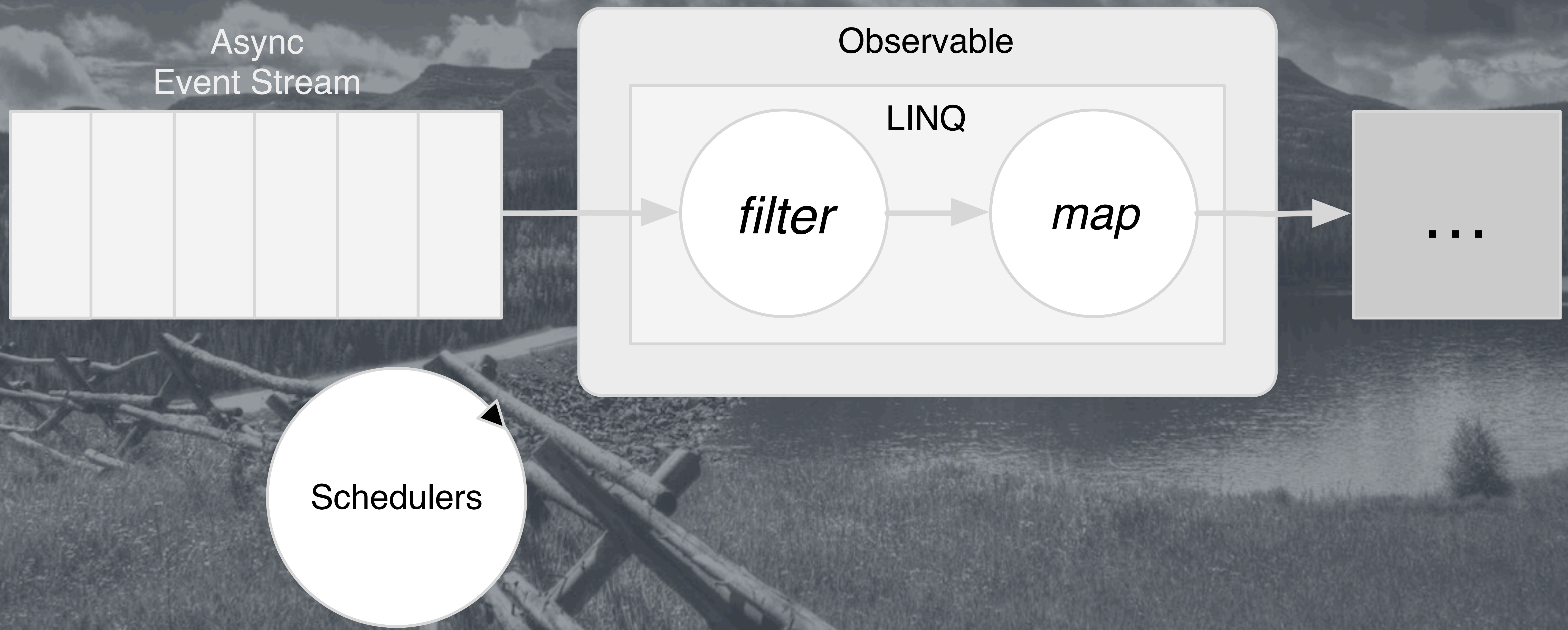

State mutation "firewalls".
Supports location transparency.
111

Reactive Extensions (Rx)

Tuesday, May 19, 15

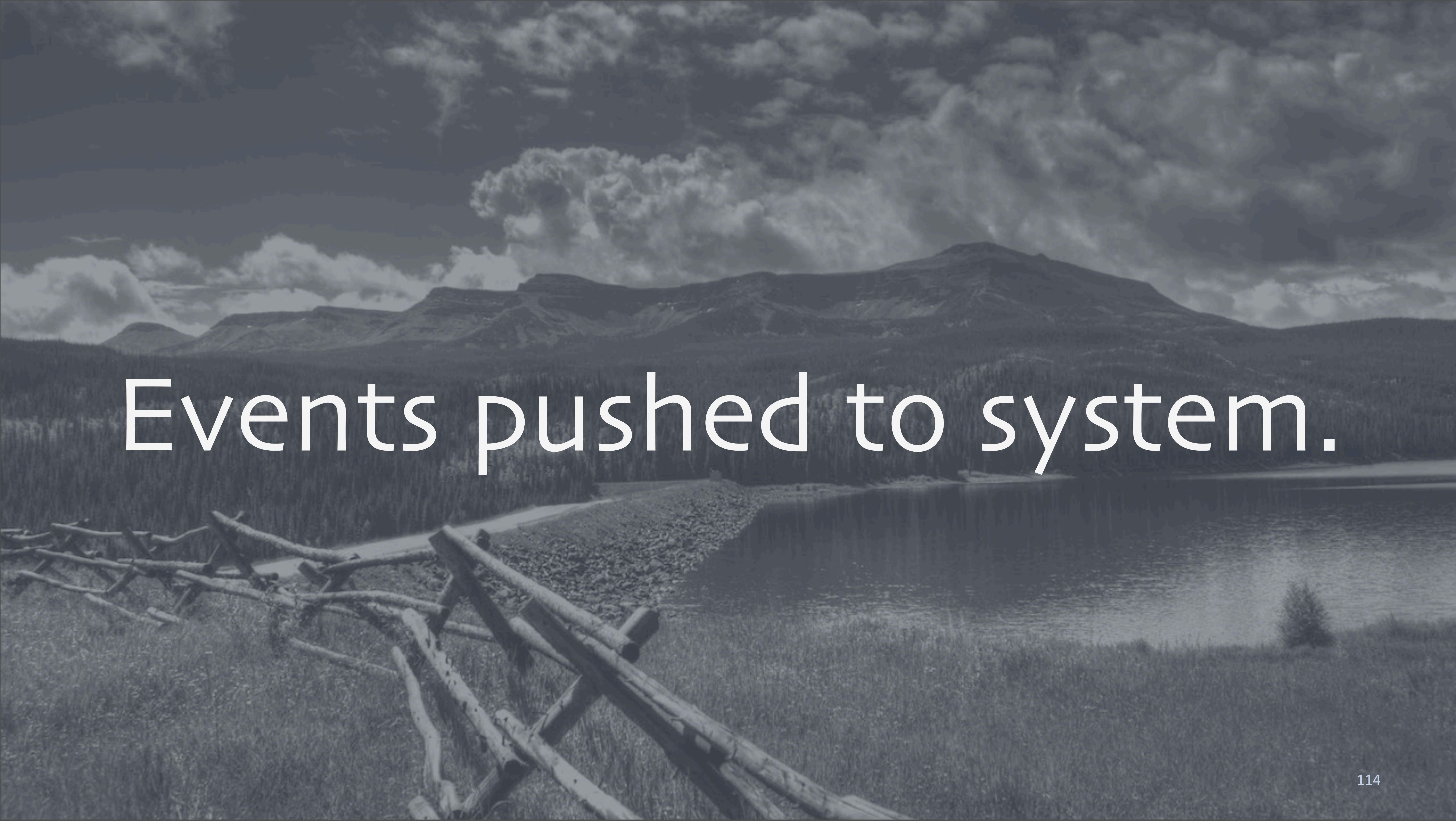
Pioneered by Erik Meijer for .NET. Now ported to several languages, including RxJava (Netflix) and React (JS – Facebook).

LINQ Rx



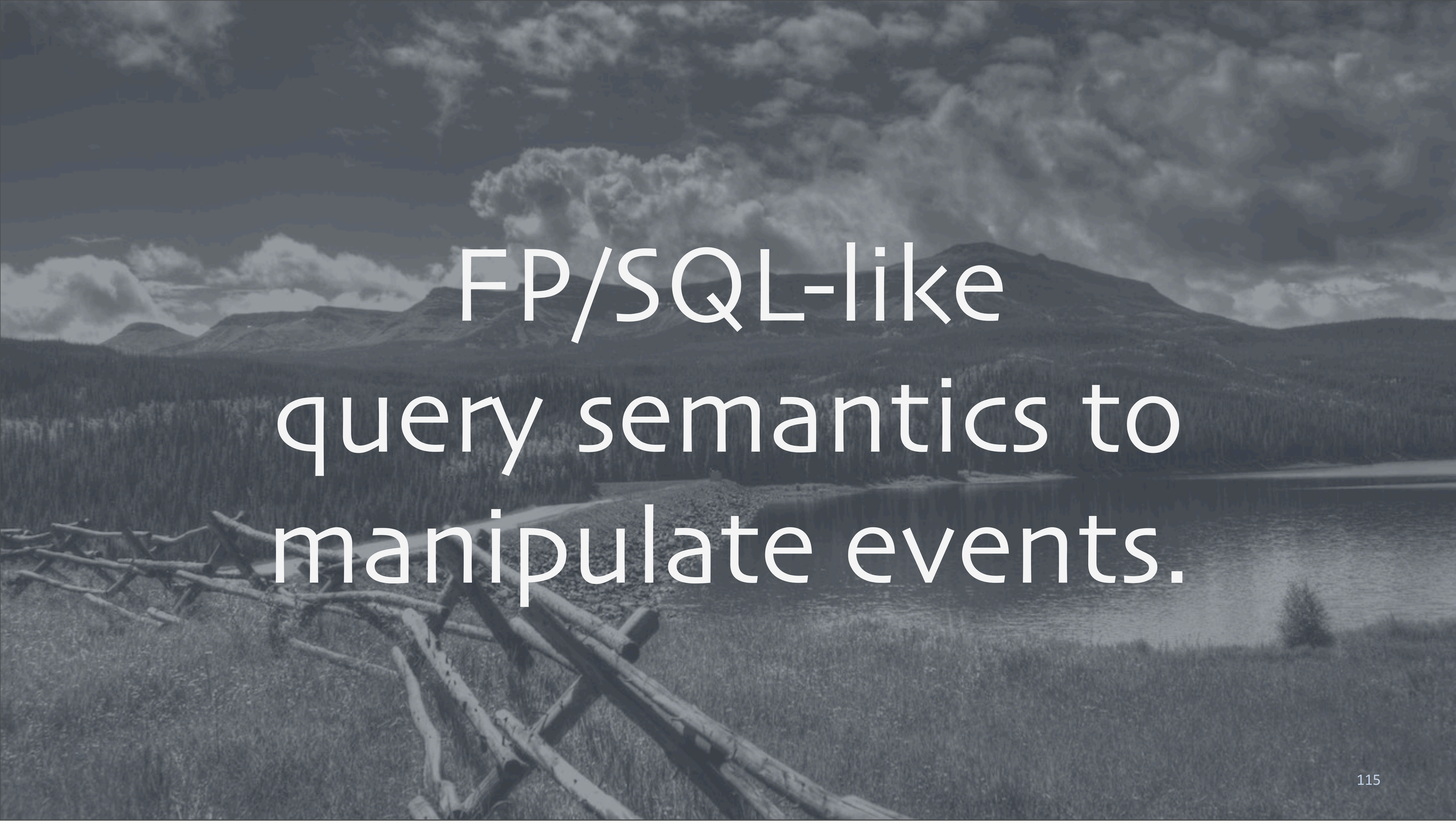
Tuesday, May 19, 15

Events are observed (an extension of the observer pattern). Operations like filtering and mapping are provided to work with the stream through LINQ (Language Integrated Query), which uses SQL-like expressions. The Schedulers are used to trigger processing.



Tuesday, May 19, 15

It’s essentially a push model.


FP/SQL-like
query semantics to
manipulate events.
115

Rx

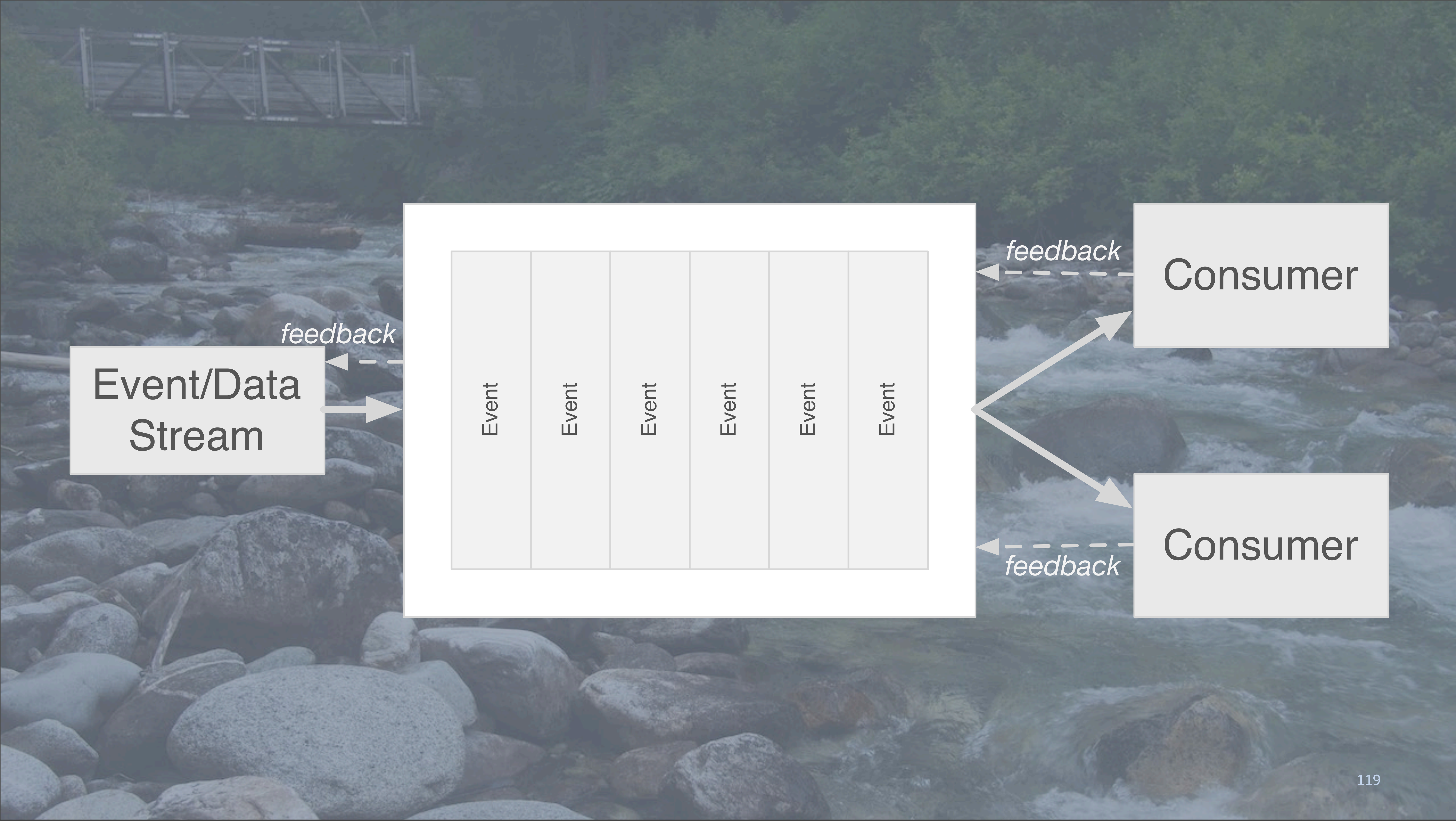
Combines Iterator and Observer into Observable. Stream oriented.

I didn't mention this before.

Tuesday, May 19, 15

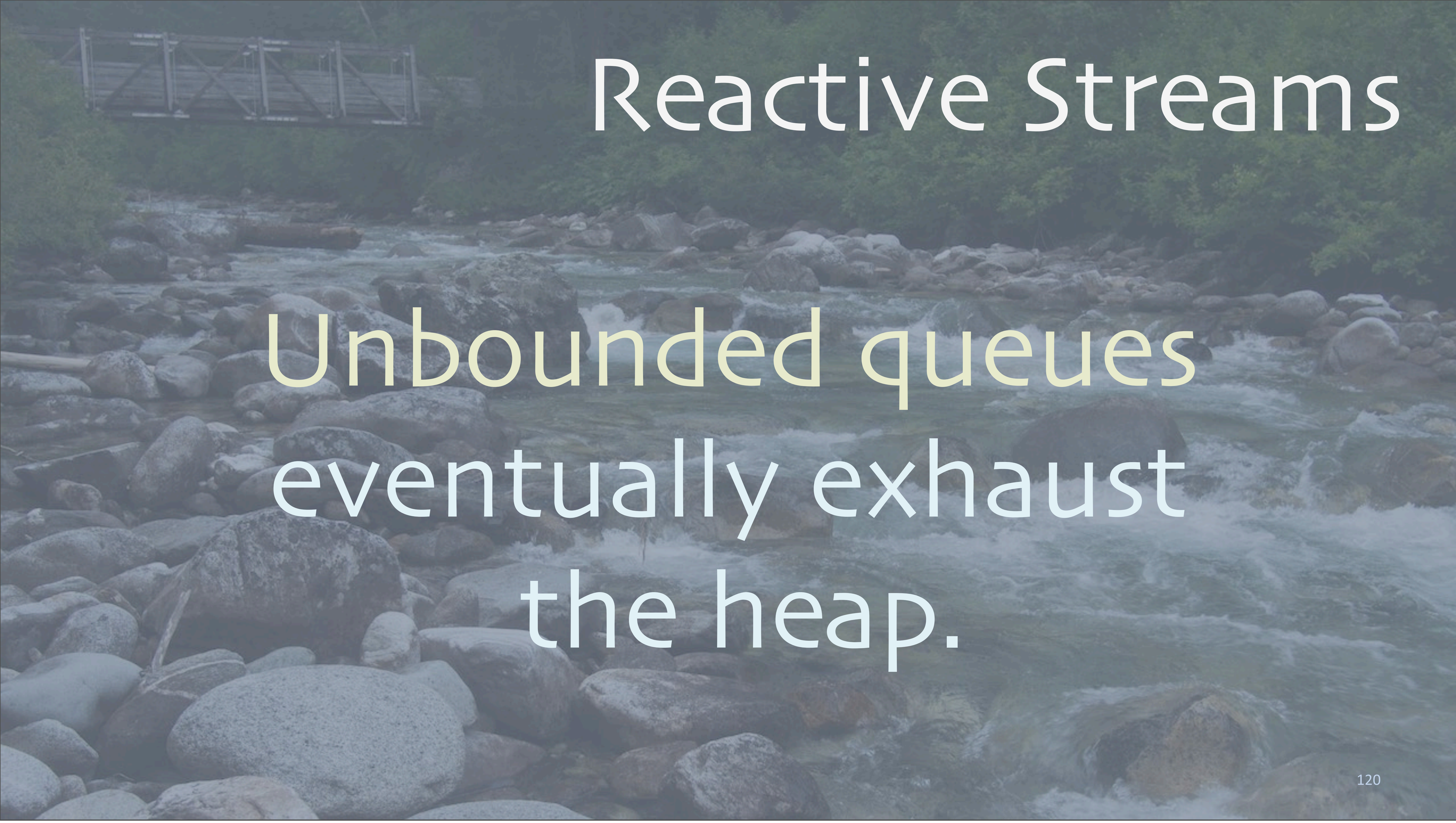
Tuesday, May 19, 15

A standard with many implementations for streaming systems with truly “reactive” behavior.
photo: Bridge Creek, North Cascades National Park, Washington State (not Colorado ;)



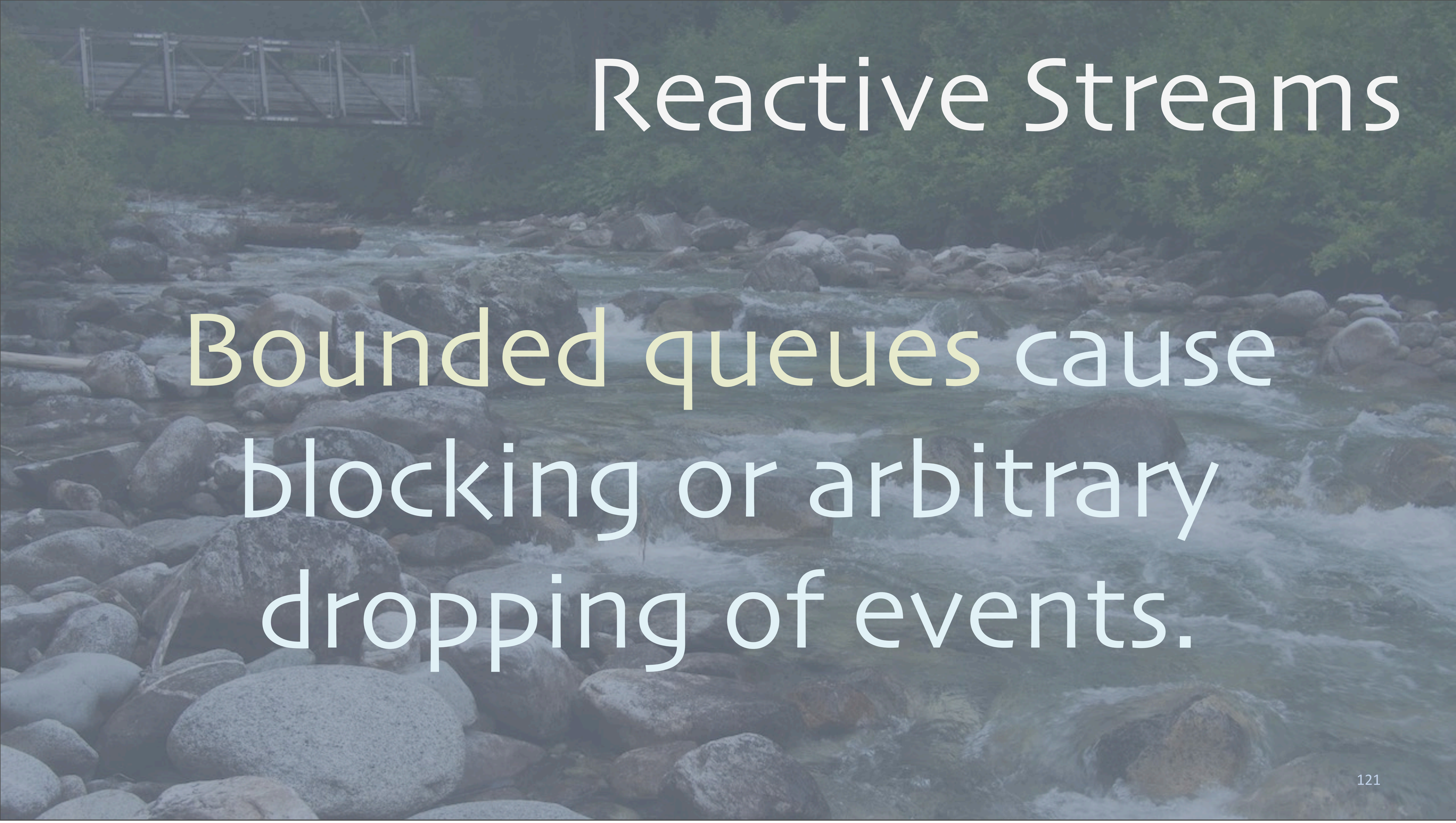
Tuesday, May 19, 15

A stream of events from some upstream producer to one or more downstream consumers. Typically, queues are used for buffering, since for asynchrony the production and consumption can't be in lock step, that is synchronized! But what happens if the queue is unbounded? Or bounded? That's where the feedback comes in.



Tuesday, May 19, 15

Any rare, low-probability event will eventually happen for a system that’s big enough or runs long enough. Any unbounded queue will eventually grow to consume all memory.



Tuesday, May 19, 15

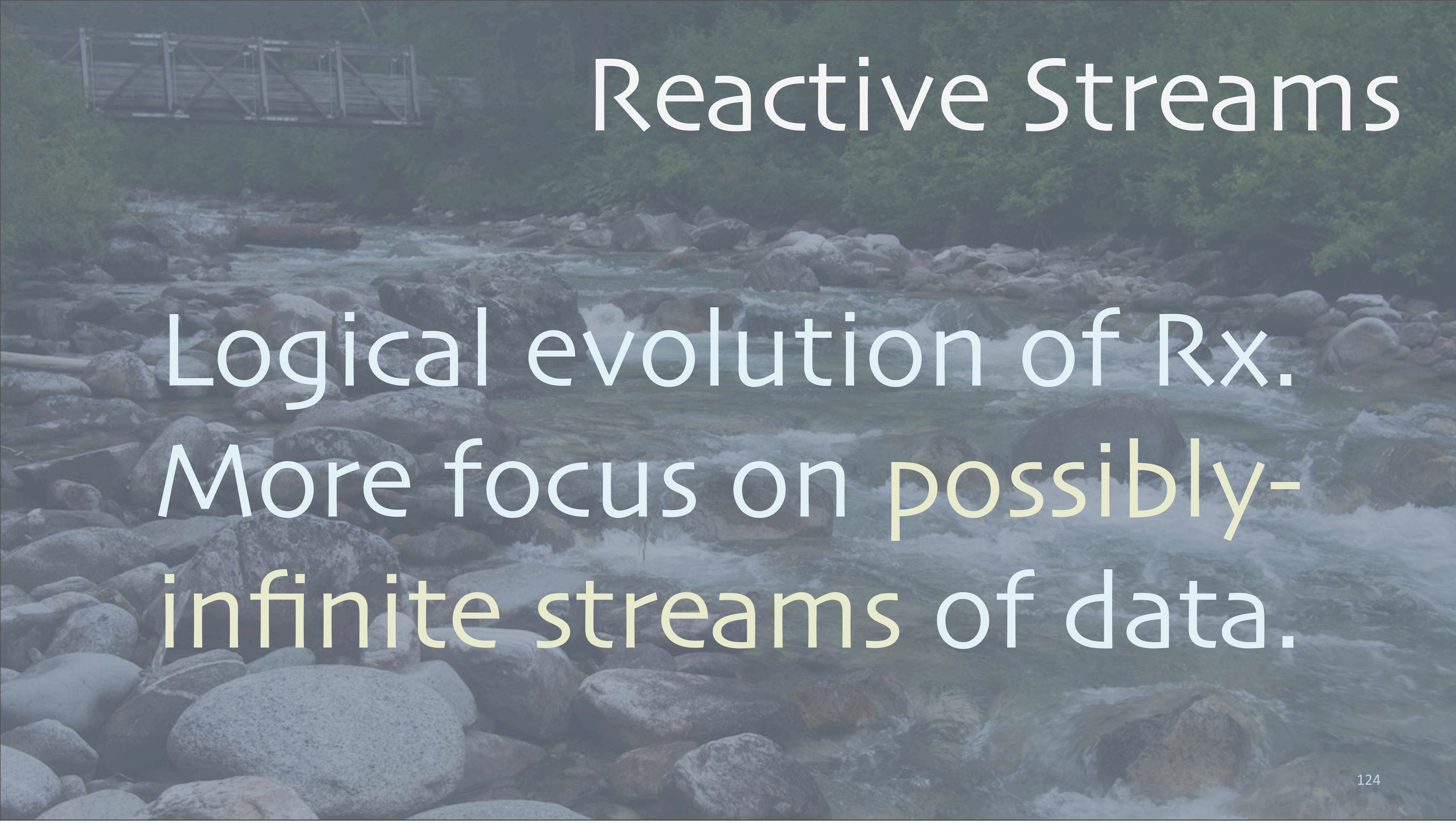
Bounded queues avoid heap exhaustion, but force arbitrary dropping of events or blocking.

Tuesday, May 19, 15

Back pressure, where the producer and consumer negotiate the flow rate dynamically, is the only way to avoid these scenarios.

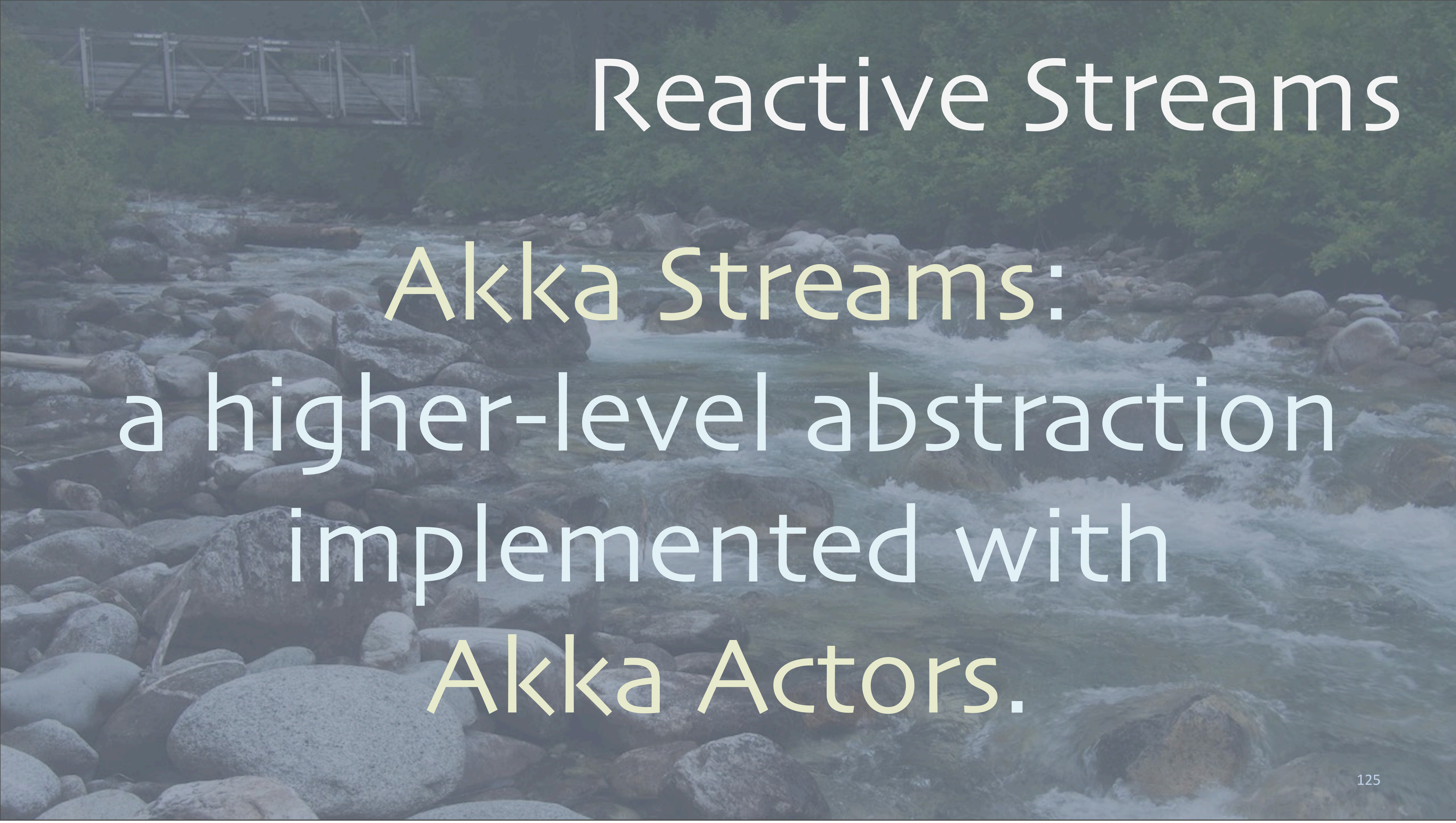
Tuesday, May 19, 15

With a system using backpressure for all flows, it’s possible to add global flow control and also strategically decide when you must drop events or take other action.



Tuesday, May 19, 15

Like Rx, RS uses functional transformations to manipulate the data. It puts slightly more emphasis on the idea of streams (possibly infinite) rather than an event loop.

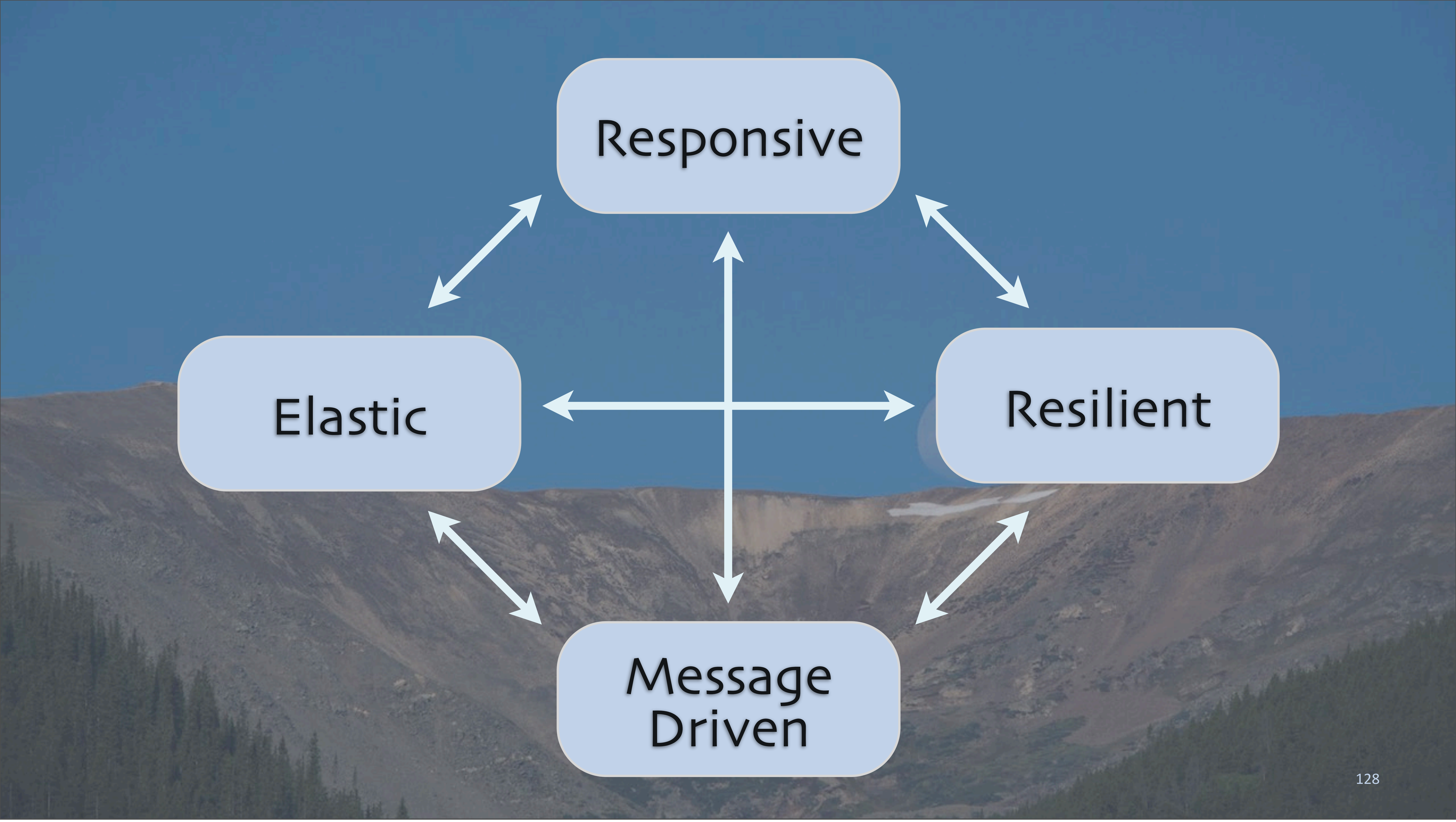


Tuesday, May 19, 15

We’re realizing that Actors are a low-level primitive and Actor systems can become unwieldy. Typesafe thinks that higher-level abstractions, like reactive streams, implemented on low-level concurrency systems, like Actors, will be the way to go for most future systems. Other implementations of RS include RxJava.


Recap
126


Four required properties
for highly-available, resilient,
and scalable services:
127

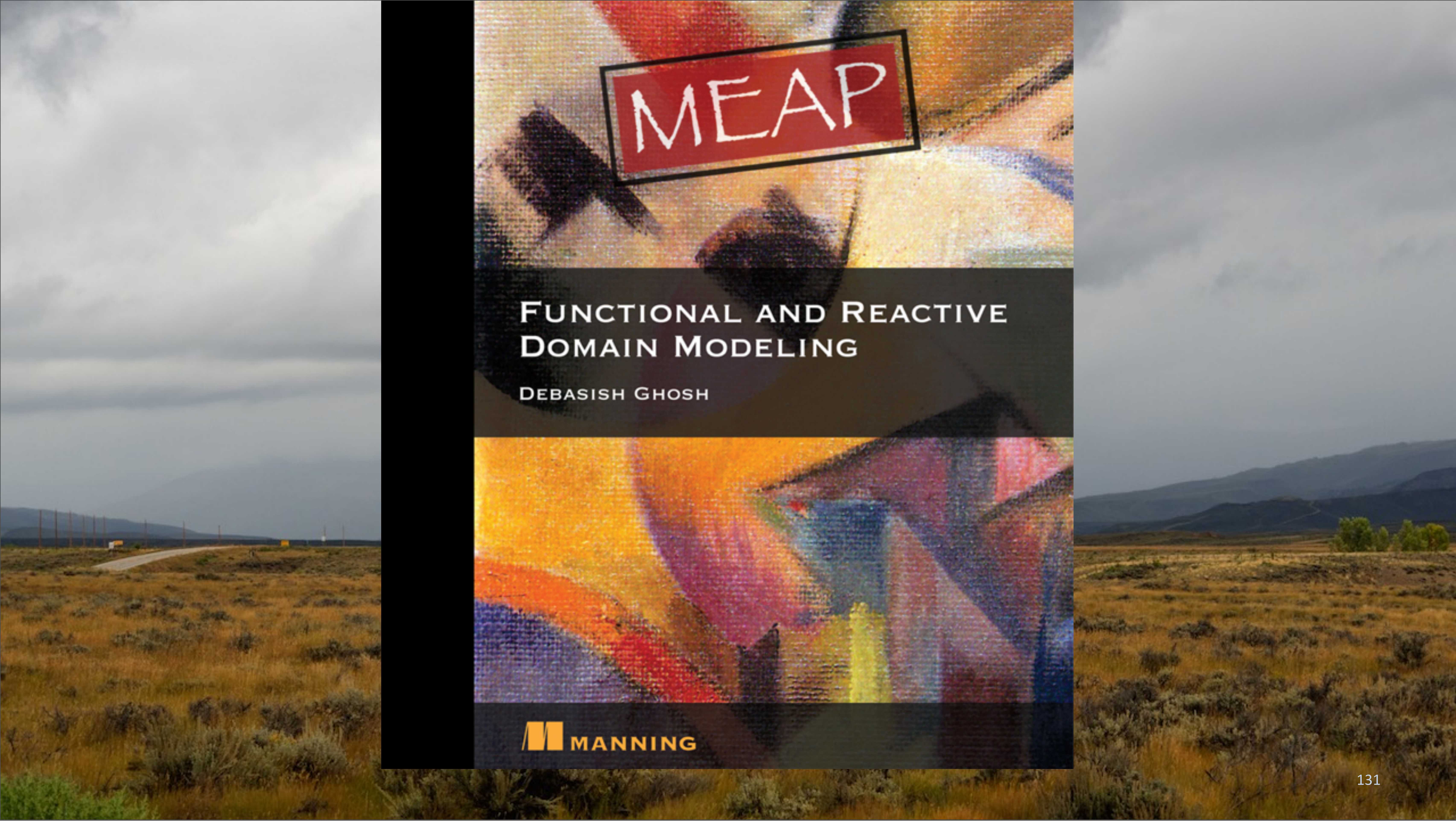

Responsive
Elastic
Resilient
Message Driven

Tuesday, May 19, 15

My primary role at Typesafe is addressing the Big Data market. We're now rolling out commercial support for Spark in non-Hadoop environments and we have other projects in the works. Talk to me if you're interested in what we're doing.

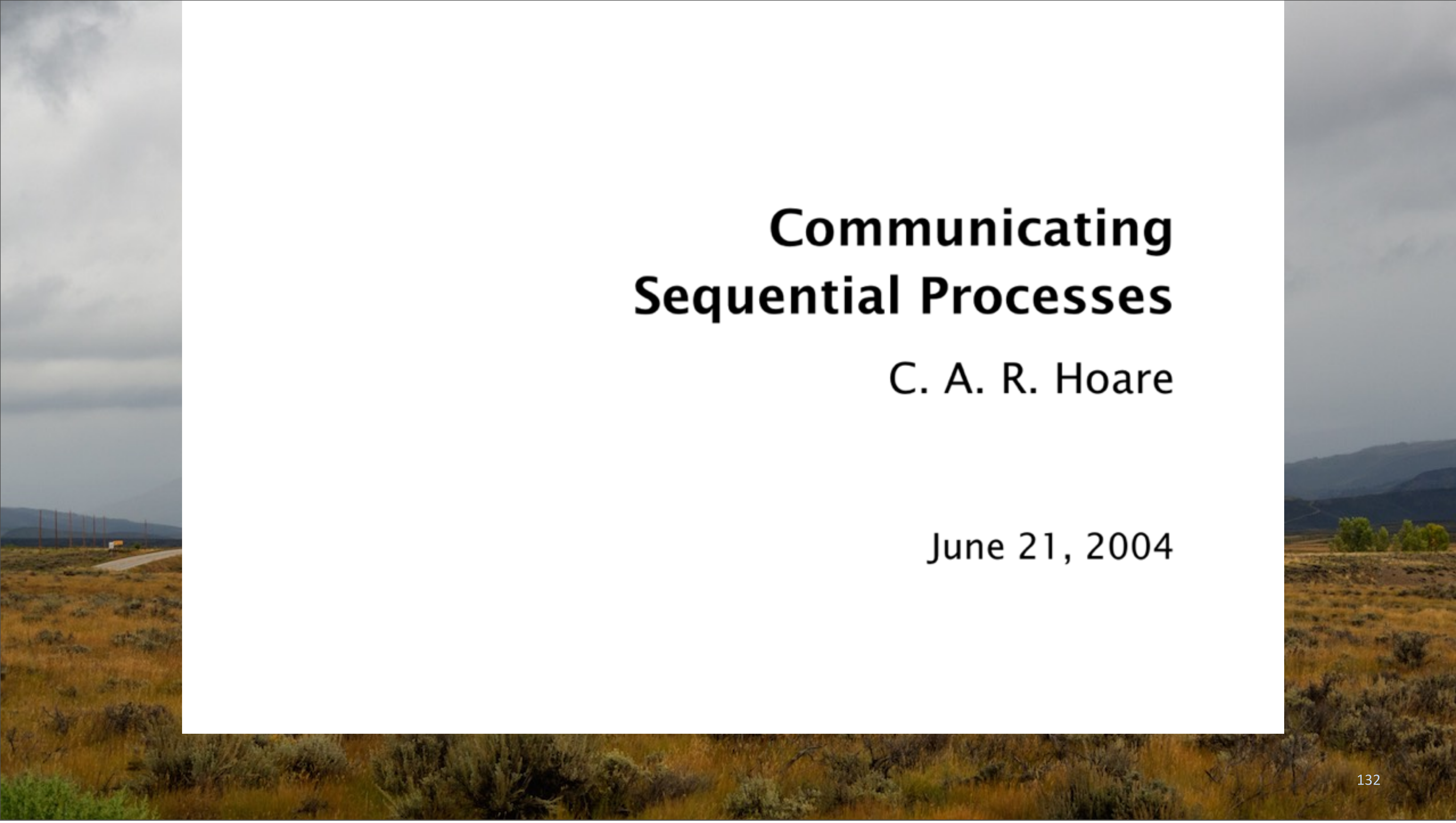
Tuesday, May 19, 15

See also links earlier in the presentation.



Tuesday, May 19, 15

Lots of interesting practical ideas for combining functional programming and reactive approaches to class Domain-Driven Design by Eric Evans.



Tuesday, May 19, 15

Hoare's book on CSP, originally published in '85 after CSP had been significantly evolved from a programming language to a theoretical model with a well-defined calculus. The book itself has been subsequently refined. The PDF is available for free.

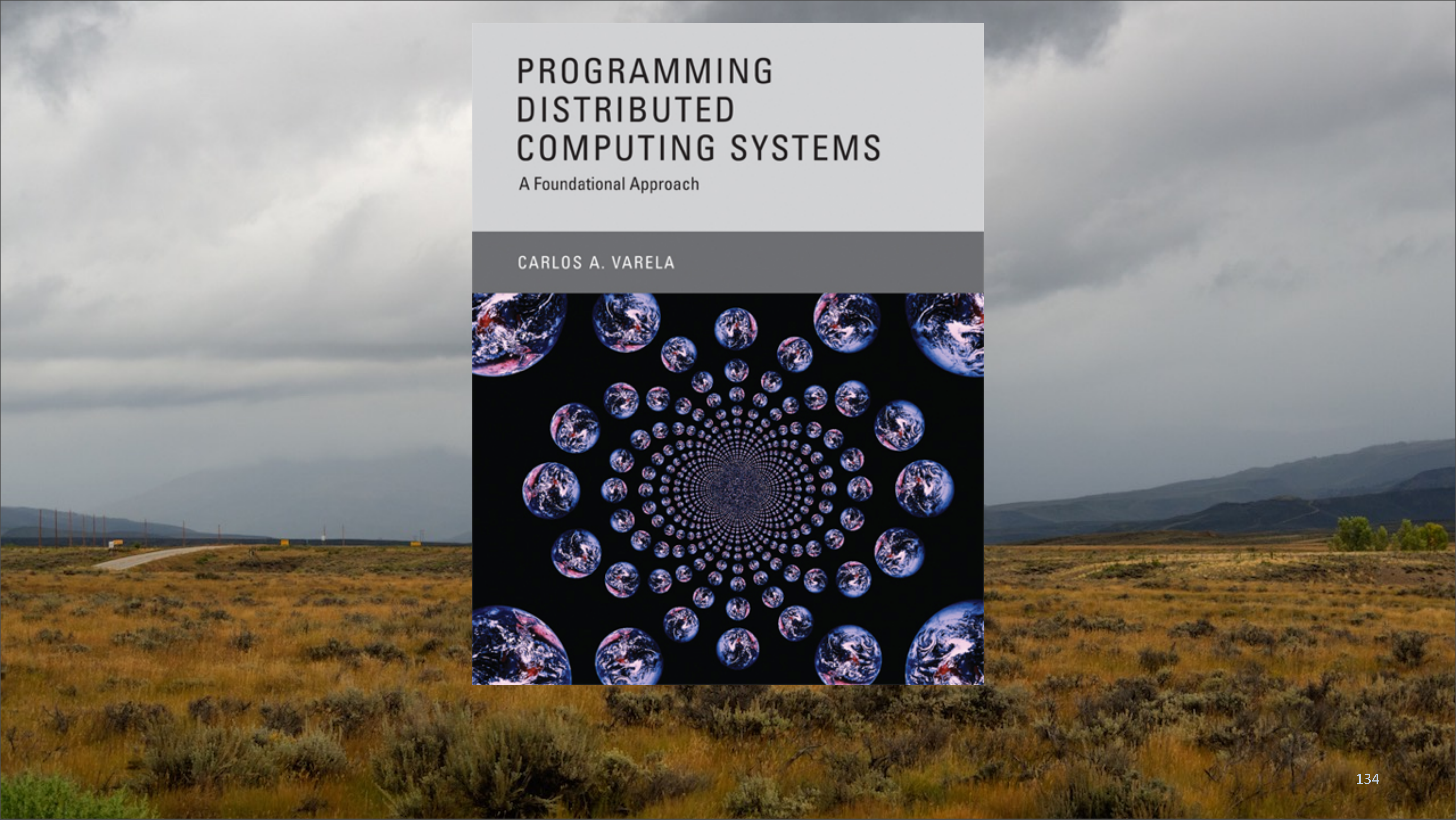
The Theory and Practice of Concurrency

A.W. Roscoe

Published 1997, revised to 2000 and lightly revised to 2005.

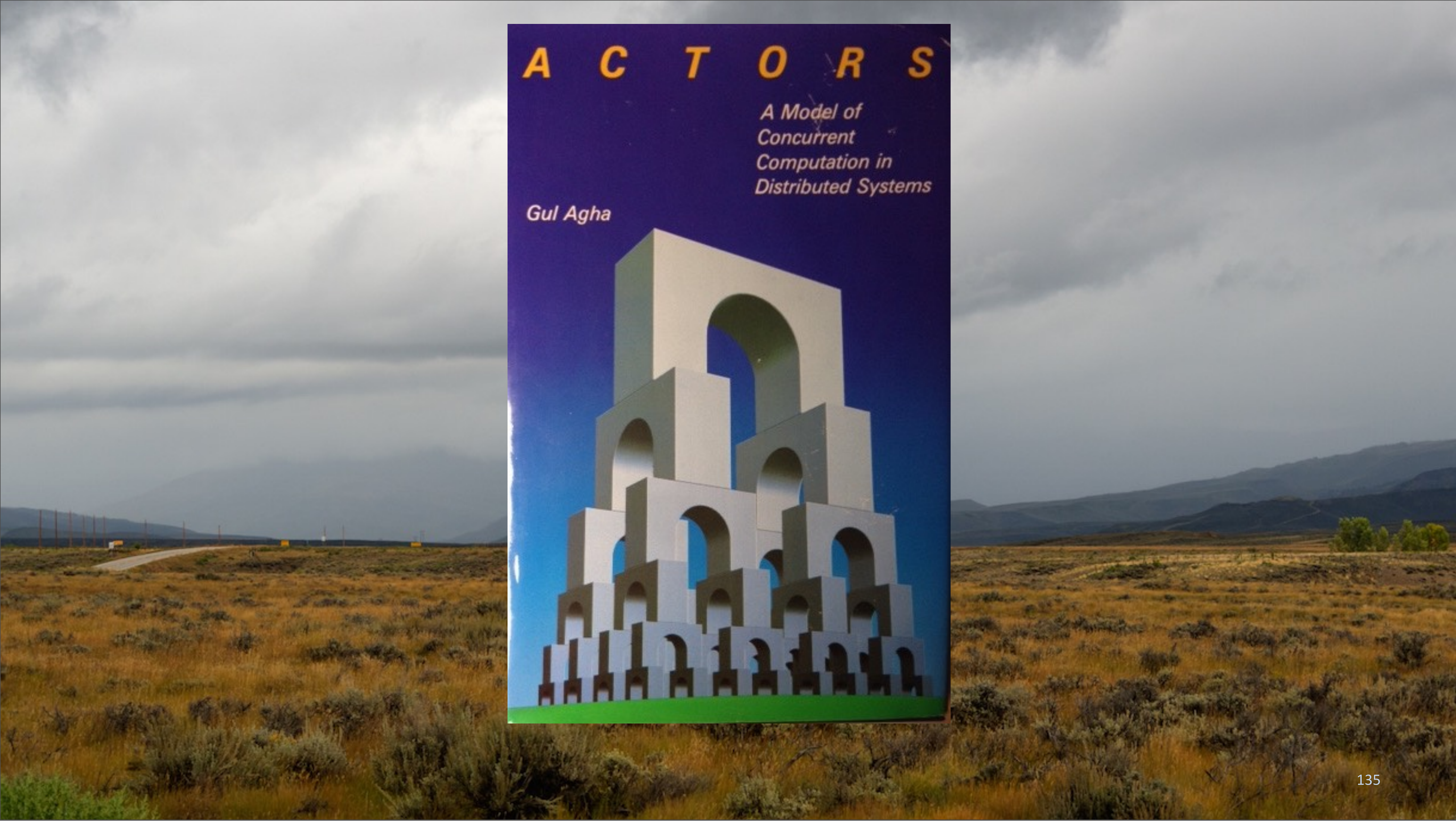
The original version is in print in April 2005 with Prentice-Hall (Pearson).

Modern treatment of CSP. Roscoe helped transform the original CSP language into its more rigorous, process algebra form, which was influenced by Milner's Calculus of Communicating Systems work. This book's PDF is available free. The treatment is more accessible than Hoare's book.



Tuesday, May 19, 15

A survey of theoretical models of distributed computing, starting with a summary of lambda calculus, then discussing the pi, join, and ambient calculi. Also discusses the actor model. The treatment is somewhat dry and could use more discussion of real-world implementations of these ideas, such as the Actor model in Erlang and Akka.

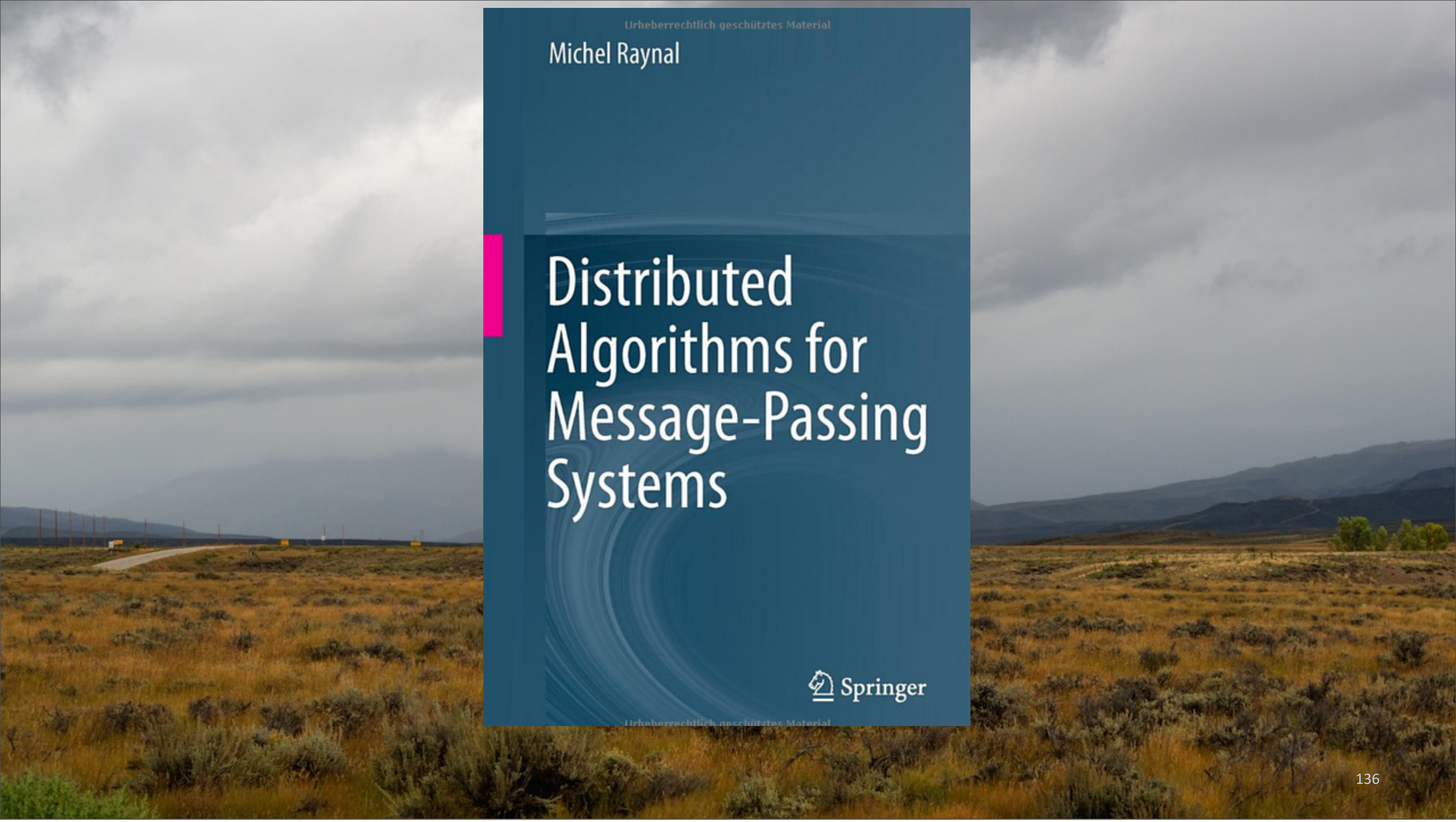


Tuesday, May 19, 15

Gul Agha was a grad student at MIT during the 80s and worked on the actor model with Hewitt and others. This book is based on his dissertation.
It doesn't discuss error handling, actor supervision, etc. as these concepts .

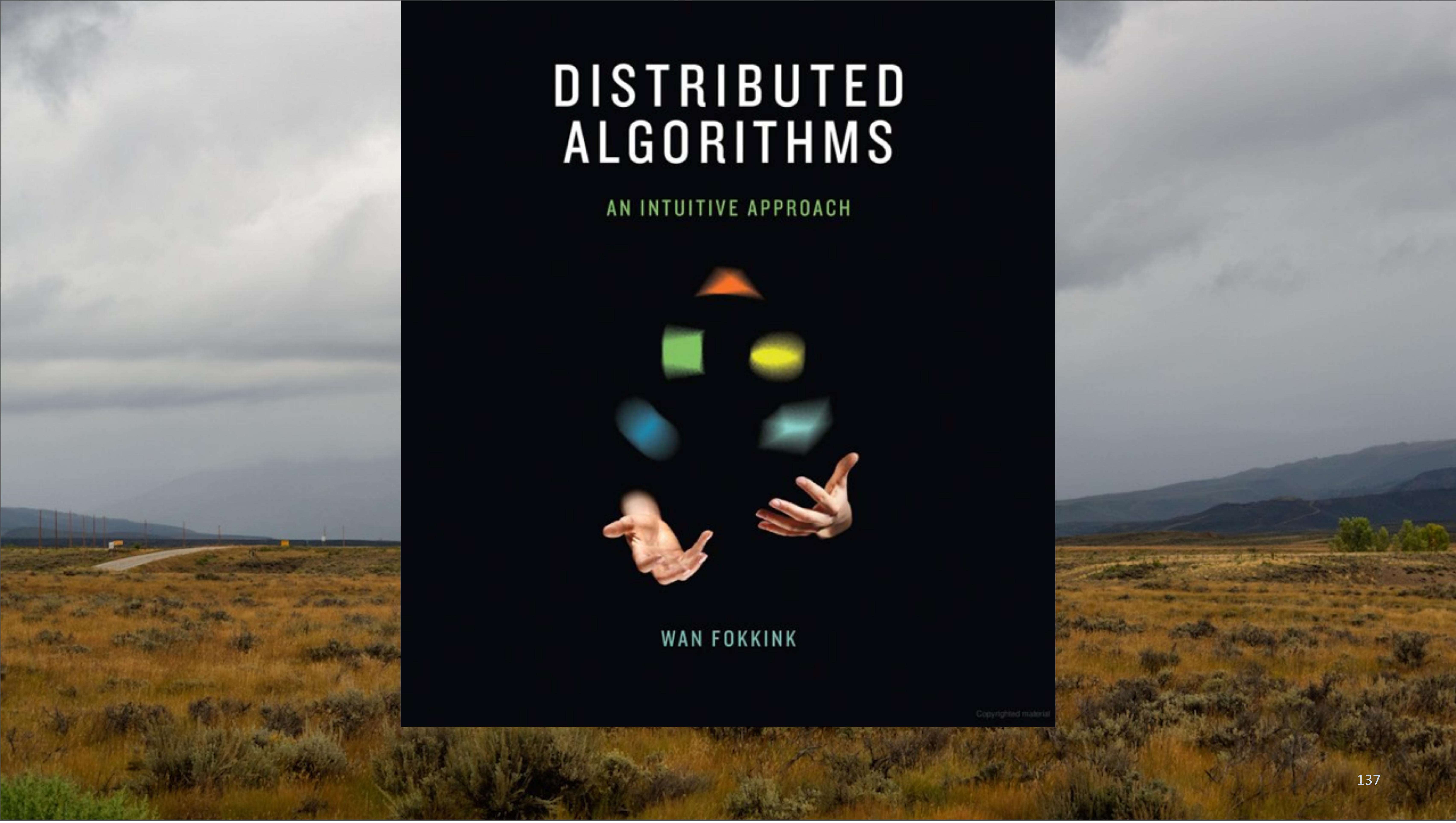
His thesis, http://dspace.mit.edu/handle/1721.1/6952, the basis for his book,http://mitpress.mit.edu/books/actors

See also Paper for a survey course with Rajesh Karmani, http://www.cs.ucla.edu/~palsberg/course/cs239/papers/karmani-agha.pdf

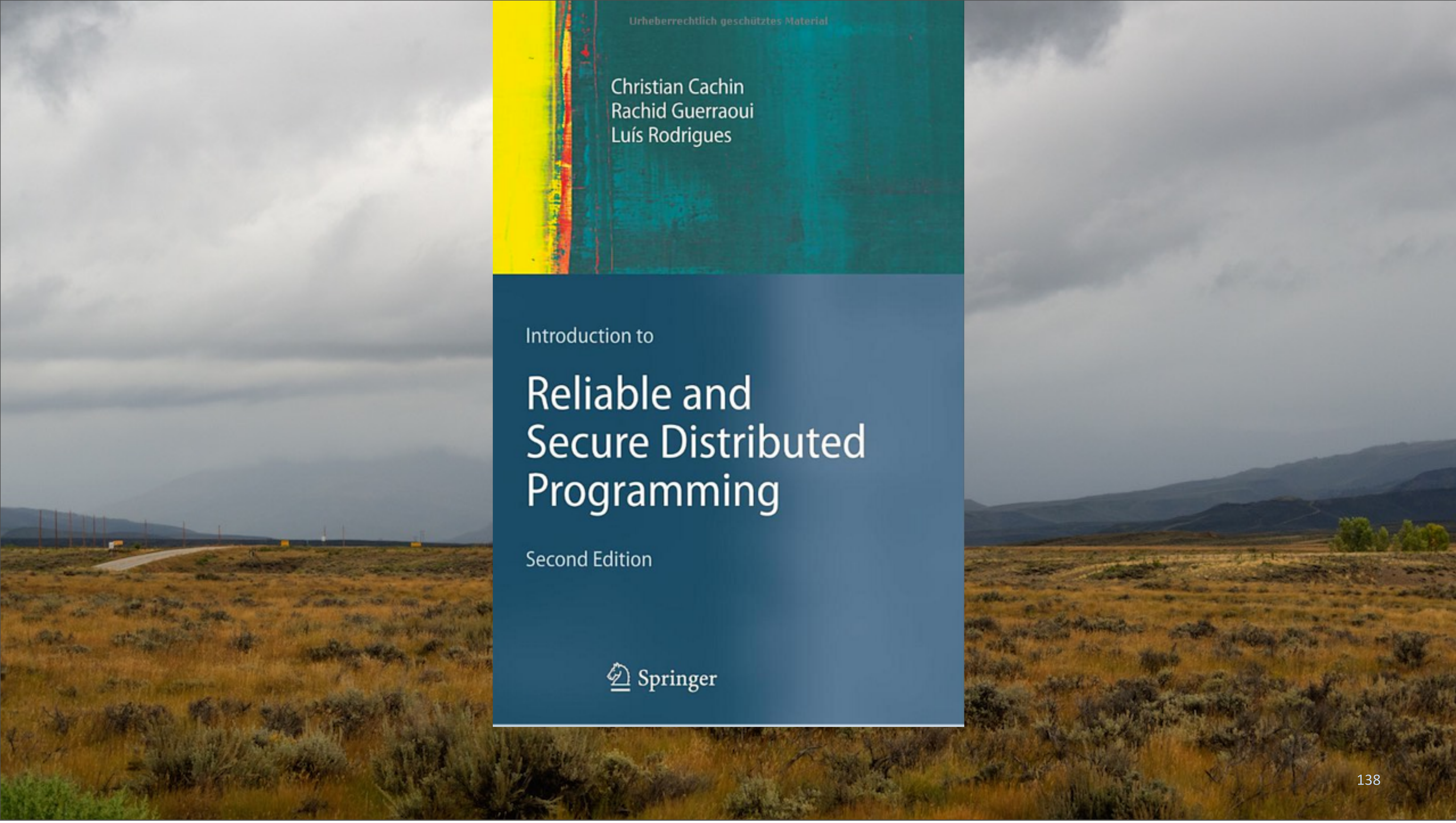


Tuesday, May 19, 15

Survey of the classic graph traversal algorithms, algorithms for detecting failures in a cluster, leader election, etc.

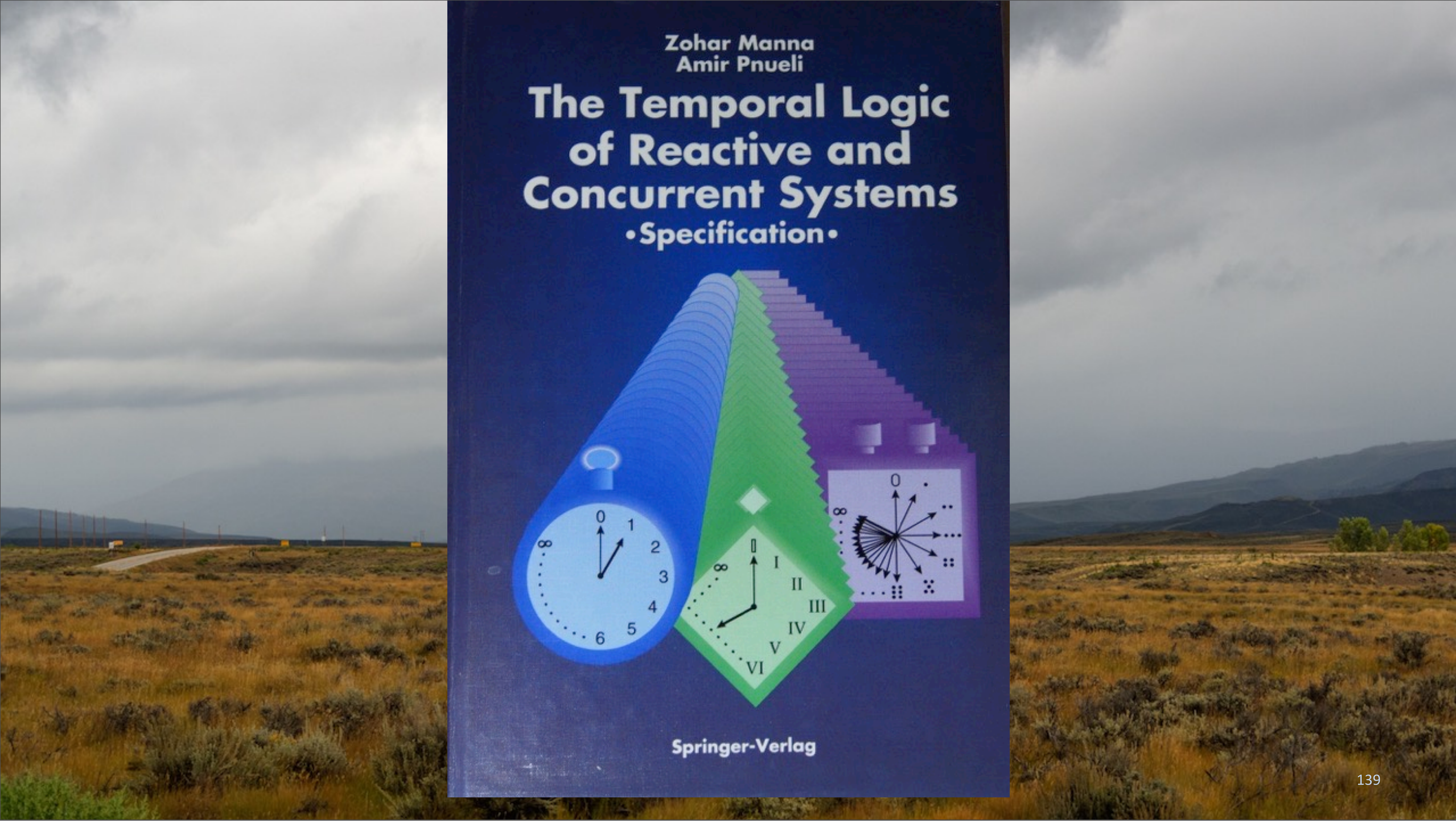


A less comprehensive and formal, but more intuitive approach to fundamental algorithms.



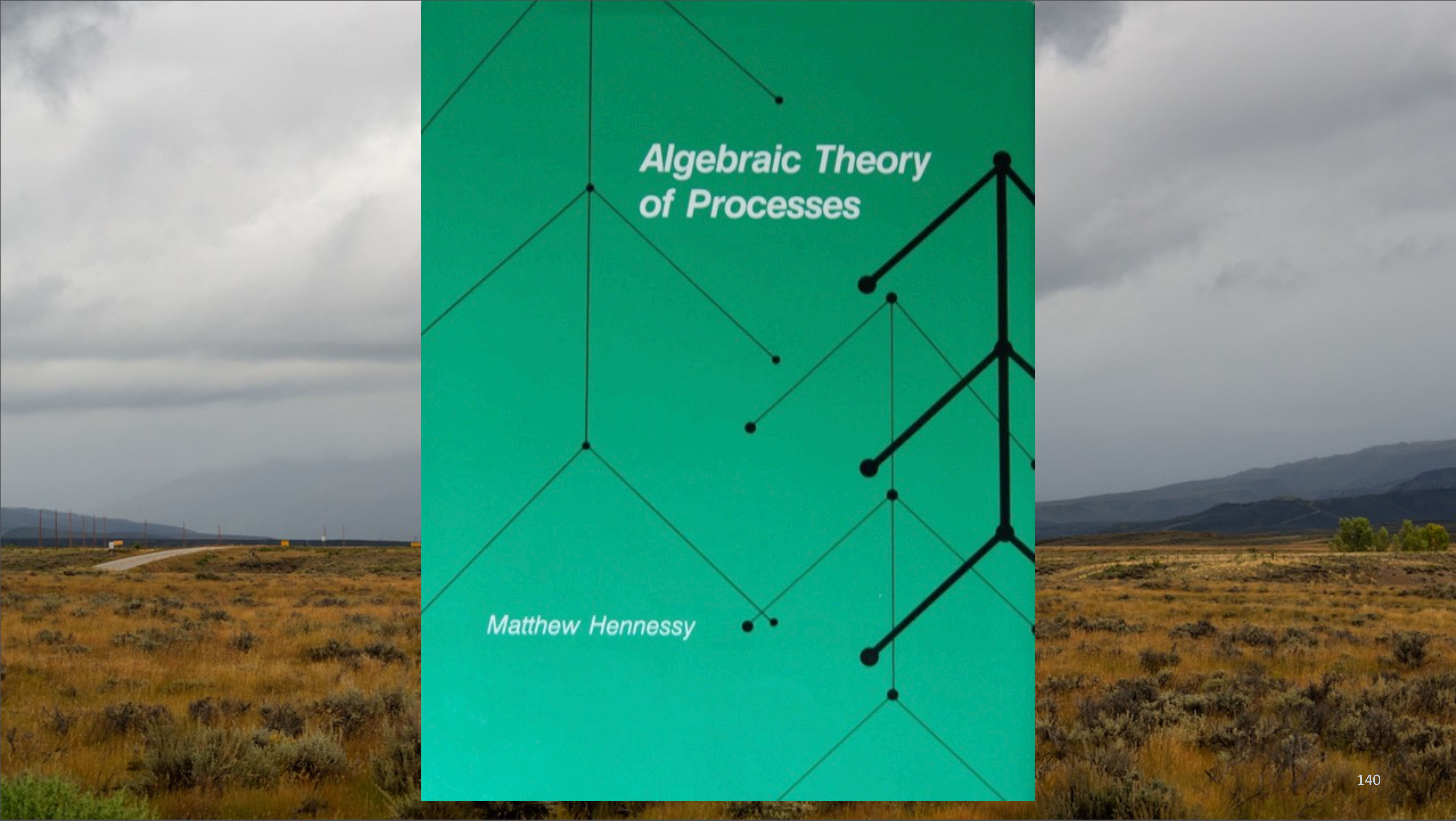
Tuesday, May 19, 15

Comprehensive and somewhat formal like Raynal's book, but more focused on modeling common failures in real systems.



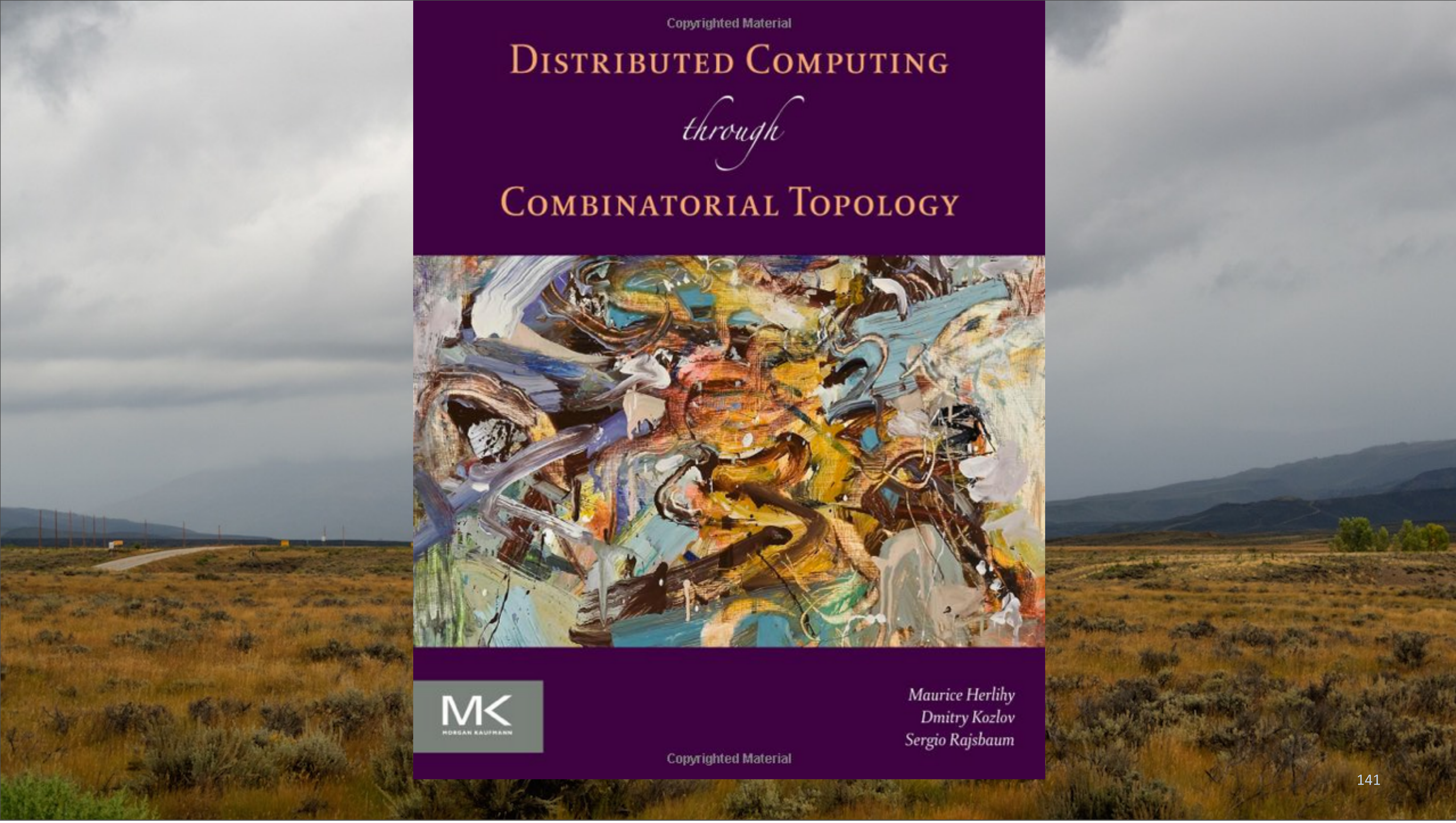
Tuesday, May 19, 15

1992: Yes, “Reactive” isn’t new ;) This book is lays out a theoretical model for specifying and proving “reactive” concurrent systems based on temporal logic. While its goal is to prevent logic errors, It doesn’t discuss handling failures from environmental or other external causes in great depth.



Tuesday, May 19, 15

1988: Another treatment of concurrency using algebra. It’s not based on CSP, but it has similar constructs.



A recent text that applies combinatorics (counting things) and topology (properties of geometric shapes) to the analysis of distributed systems. Aims to be pragmatic for real-world scenarios, like networks and other physical systems where failures are practical concerns.

http://mitpress.mit.edu/books/engineering-safer-world

Farther afield, this book discusses safety concerns from a systems engineering perspective.