Journées GDR GPL

# Engineering Scale: Software and Distribution for Tomorrow's World

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INVENTEURS DU MONDE NUMÉRIQUE

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ECOLE SUPERIEURE
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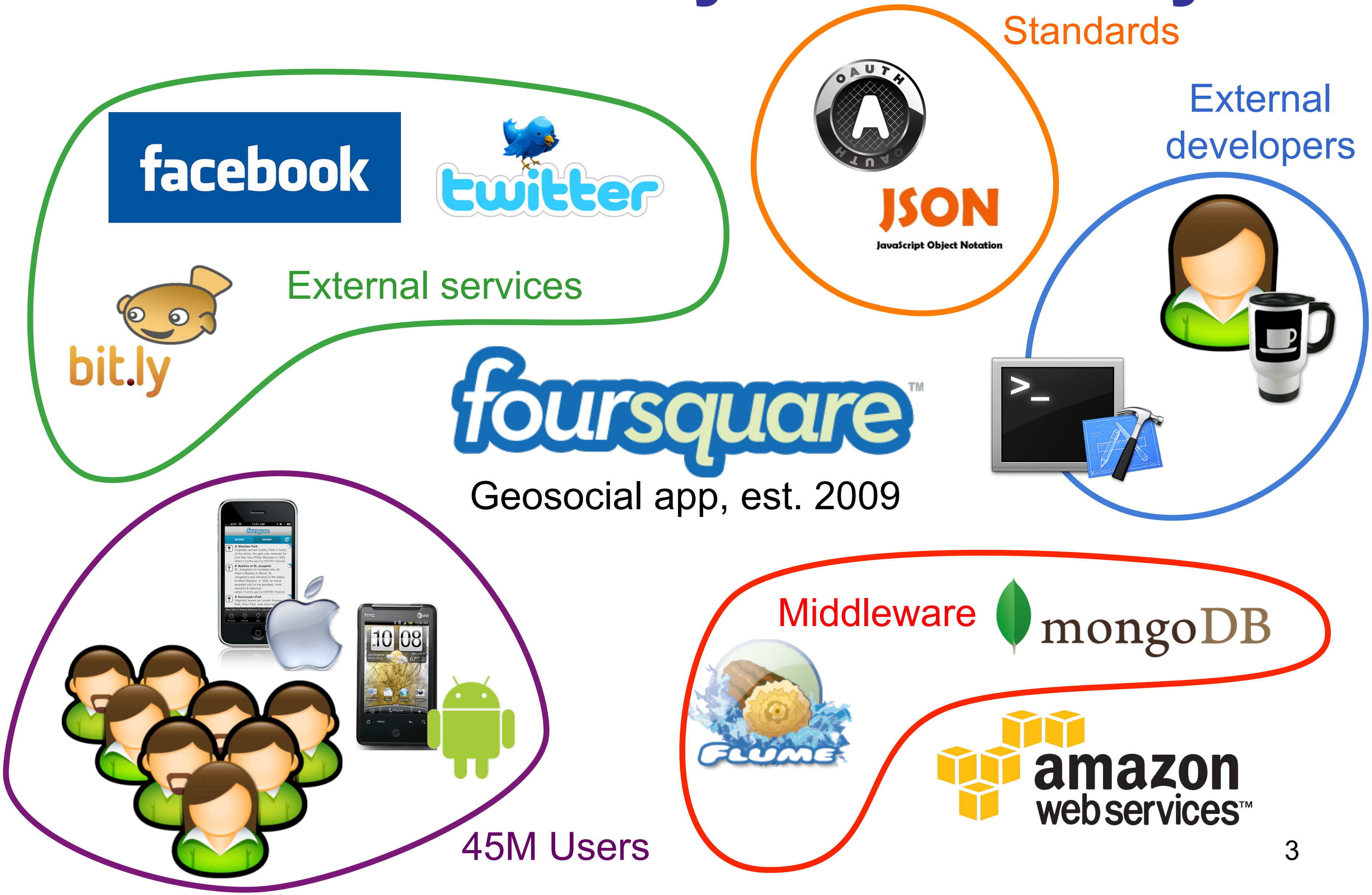
# Ideal software artefact

➔ structured, predictable, open, evolvable

# A Distributed System Today …



Standards

External developers

External services

Geosocial app, est. 2009

Middleware

45M Users

Today's distributed systems

→ sprawling, chaotic, complex, unmanageable?

# Outline

- A call to arms: engineering large scale
- Examples of ways forward

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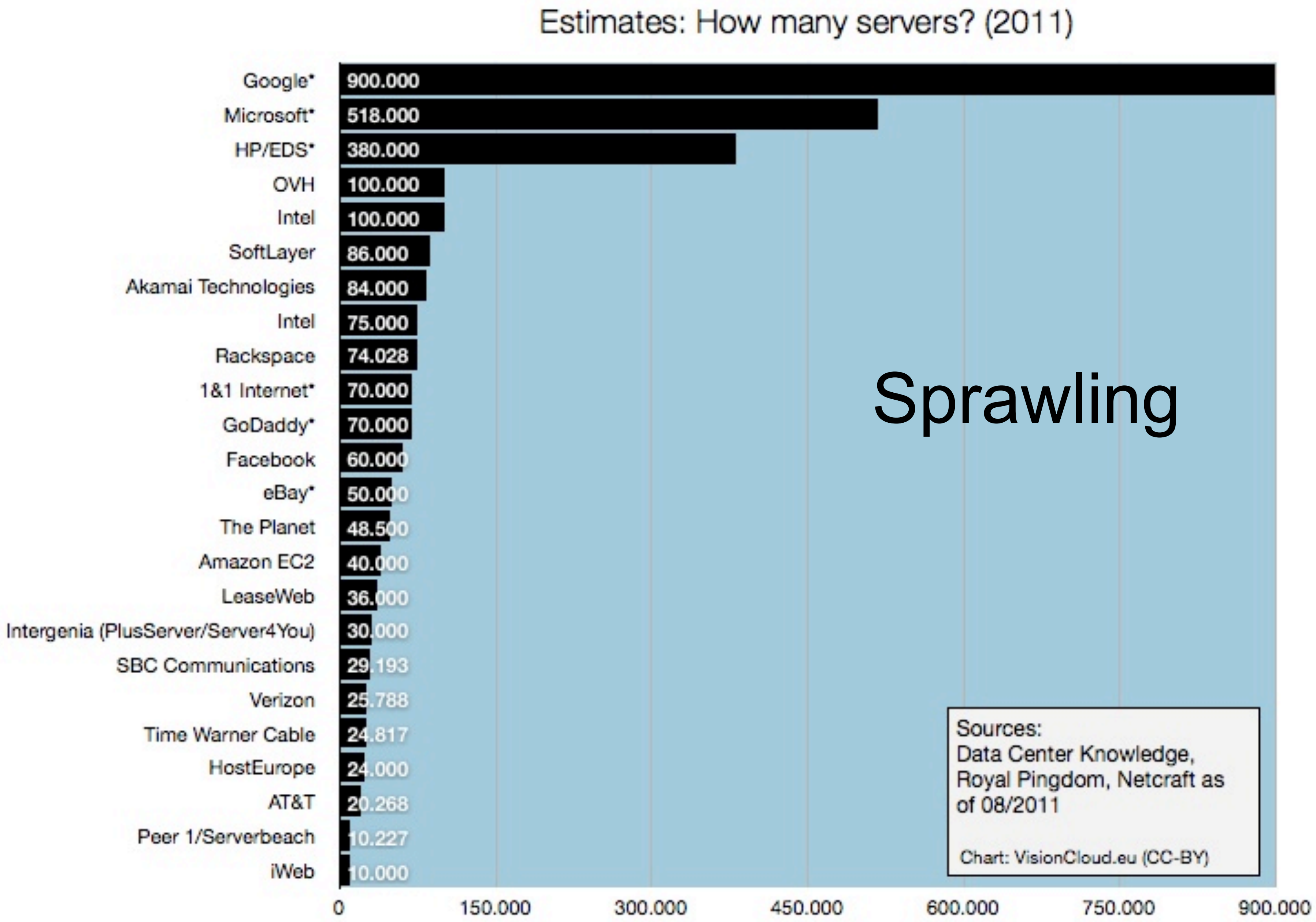
- Examples of ways forward

Today's distributed systems

- ➔ sprawling, chaotic, complex, unmanageable?



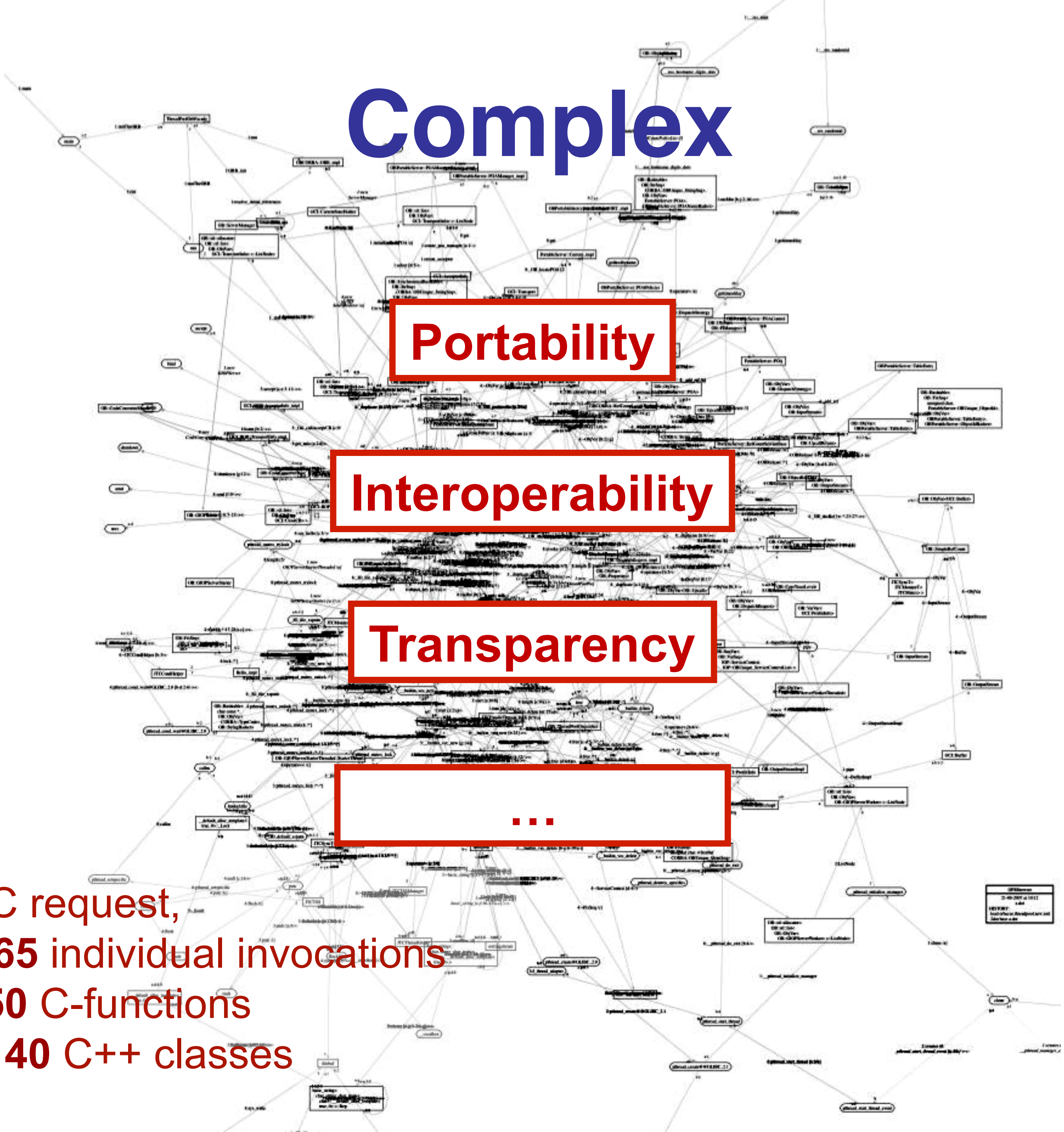
Sprawling

Source: "How Many Servers Worldwide?", Mirko Lorenz, http://www.visioncloud.eu/content.php?s=191,324

Chaotic

http://www.google.com/about/datacenters/gallery/#/

# Complex



Portability

Interoperability

Transparency

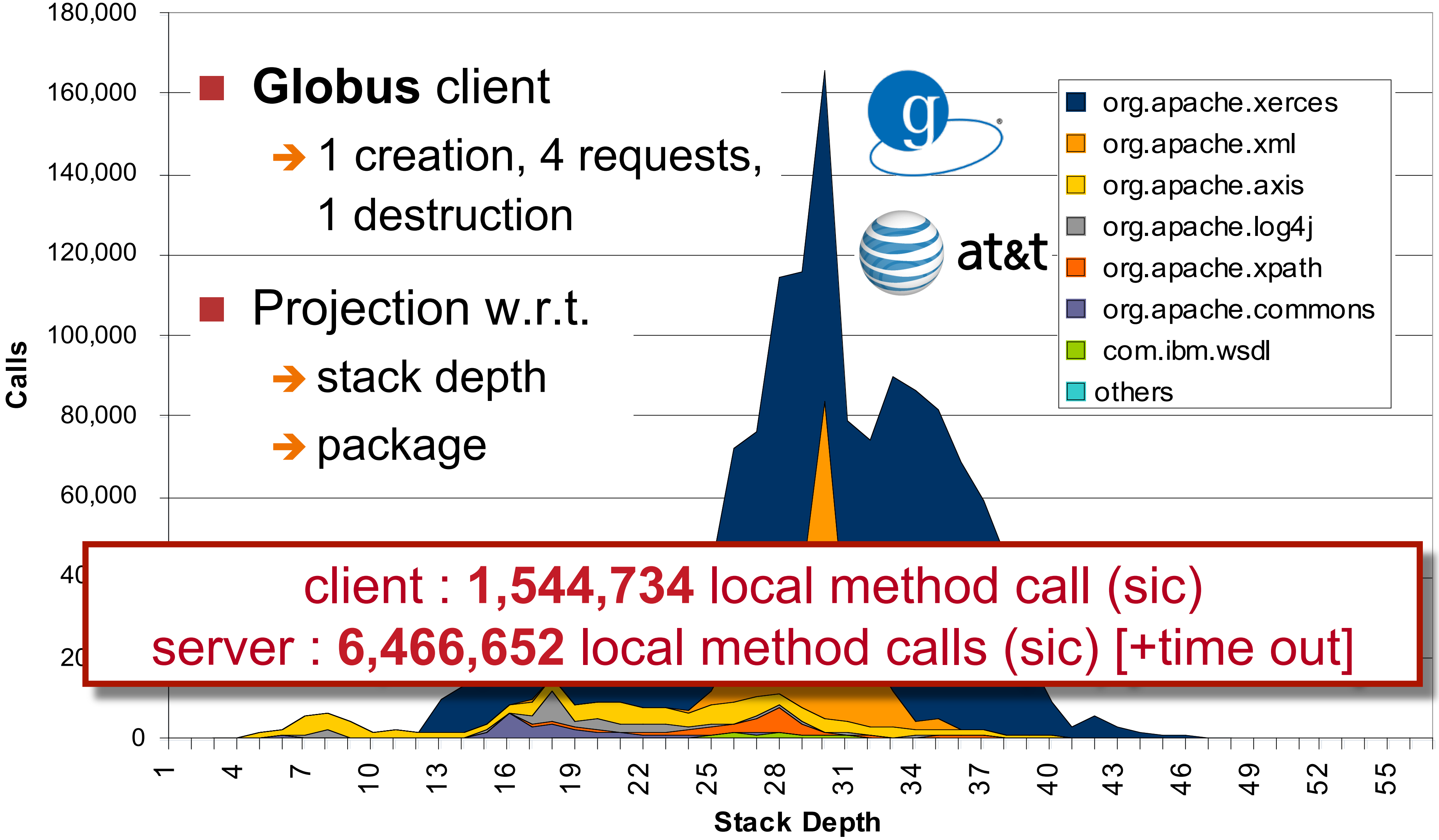
…

**one** RPC request,

- **2065** individual invocations
- > **50** C-functions
- > **140** C++ classes

Source: [TKF2009]

# Unmanageable?

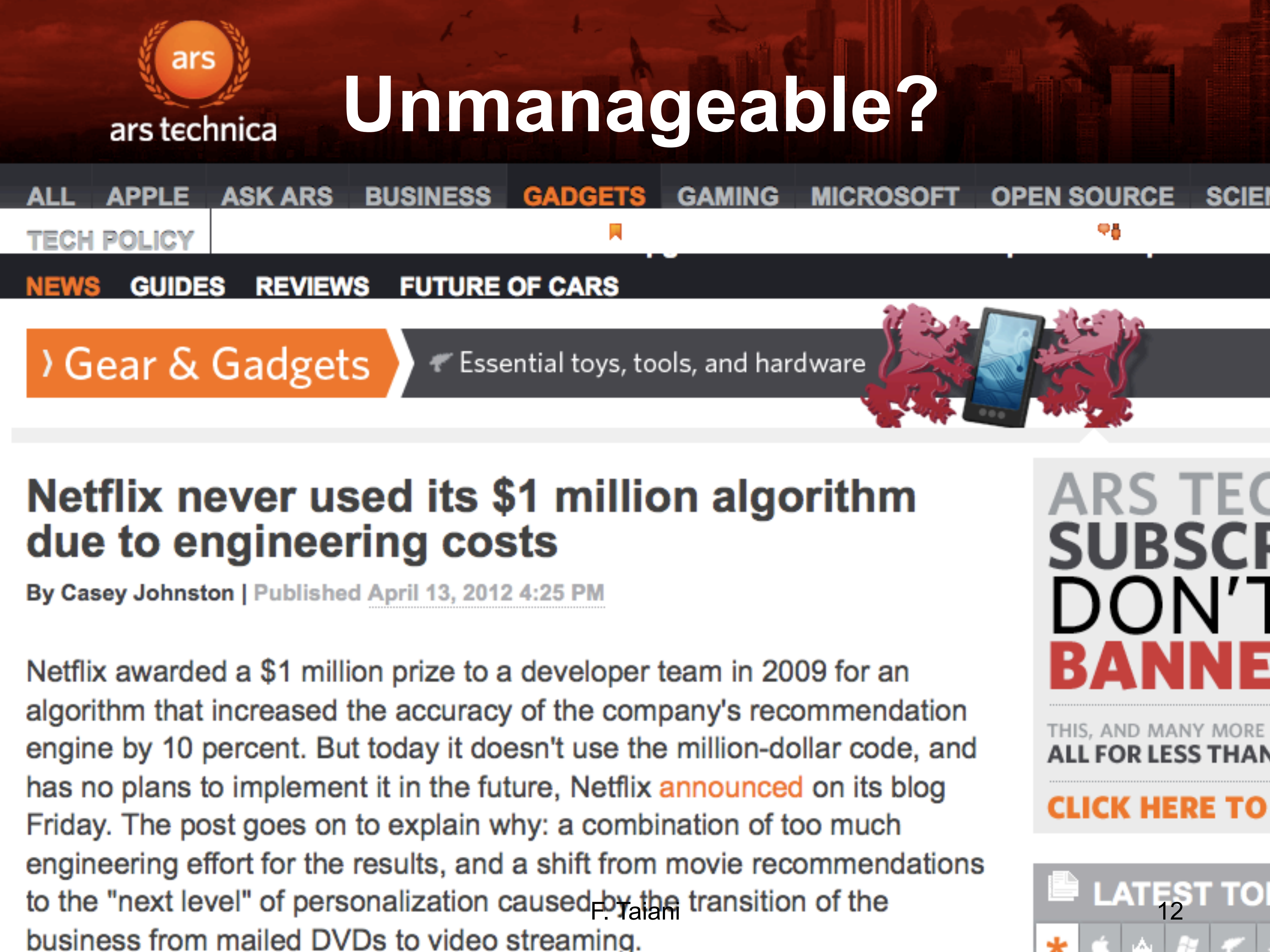


- **Globus** client
  - ➔ 1 creation, 4 requests, 1 destruction
- Projection w.r.t.
  - ➔ stack depth
  - ➔ package

client : **1,544,734** local method call (sic)
server : **6,466,652** local method calls (sic) [+time out]

The Impact of Web Service Integration on Grid Performance. Taïani, Hiltunen, Schlichting, HPDC-14, 2005

# Unmanageable?



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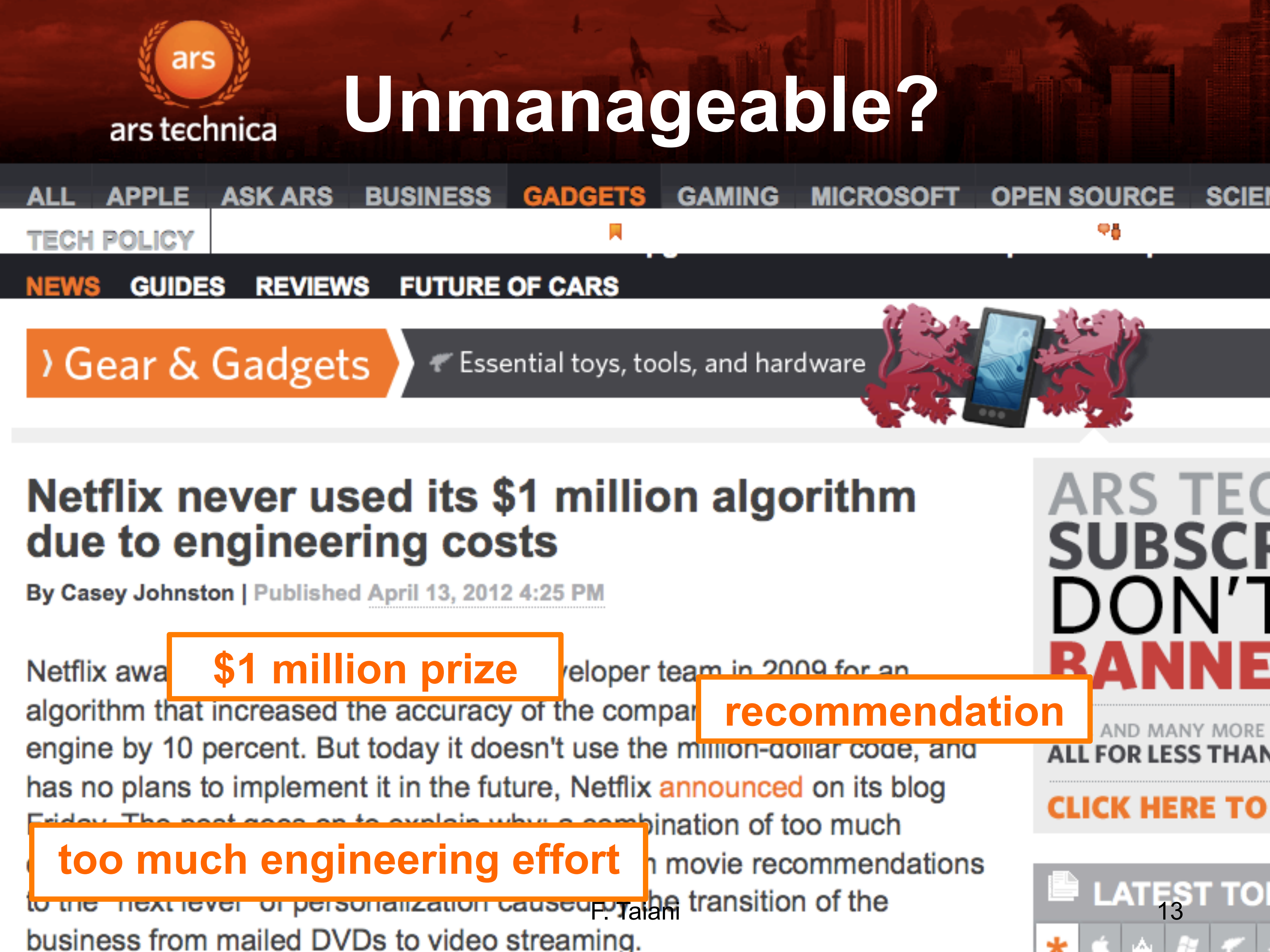
TECH POLICY
NEWS GUIDES REVIEWS FUTURE OF CARS
› Gear & Gadgets
Essential toys, tools, and hardware

## Netflix never used its $1 million algorithm due to engineering costs

By Casey Johnston | Published April 13, 2012 4:25 PM

Netflix awarded a $1 million prize to a developer team in 2009 for an algorithm that increased the accuracy of the company's recommendation engine by 10 percent. But today it doesn't use the million-dollar code, and has no plans to implement it in the future, Netflix announced on its blog Friday. The post goes on to explain why: a combination of too much engineering effort for the results, and a shift from movie recommendations to the "next level" of personalization caused by the transition of the business from mailed DVDs to video streaming.

# Unmanageable?



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$1 million prize

recommendation

too much engineering effort

NETFLIX

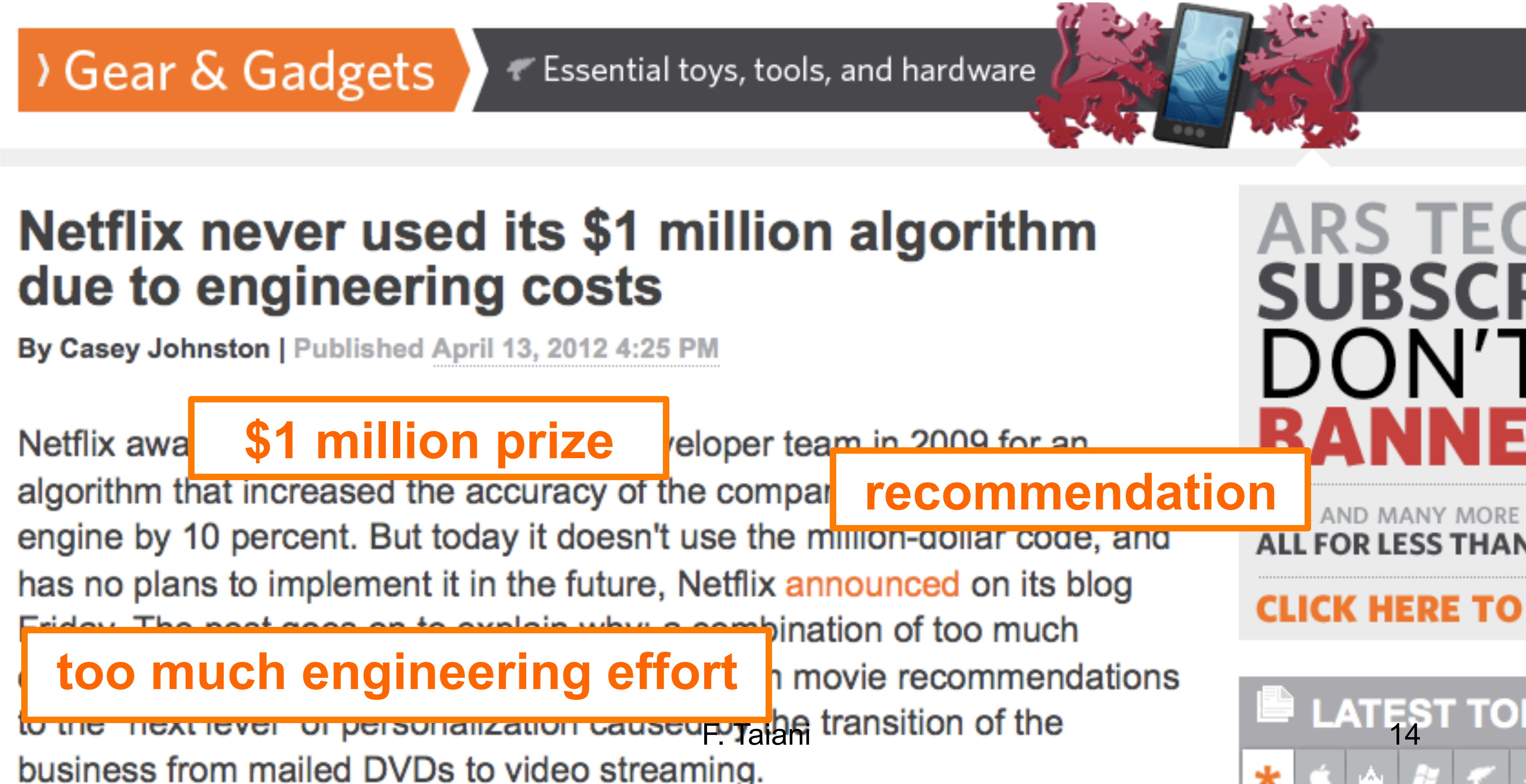
amazon webservices™

Apache

**Large**

**Dynamic**

**Complex**



› Gear & Gadgets

Essential toys, tools, and hardware

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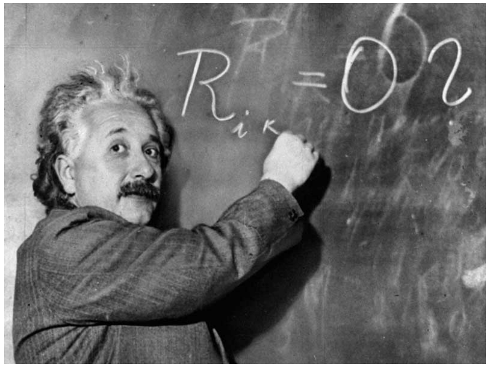
$1 million prize

recommendation

too much engineering effort

# Why is distribution hard?

- **Information** takes **time** to travel
  - → Some DS protocols inspired from general relativity



- Machines and networks **fail**
  - → If MTTF 4 years: 1M machines → 1 failure every 2 minutes

# Impossibility Results

**Asynchronous** system with **crash** failures

- **Consensus** impossible (even if only one node crashes)
- **C**onsistency + **A**vailability + **P**artition tol. Impossible

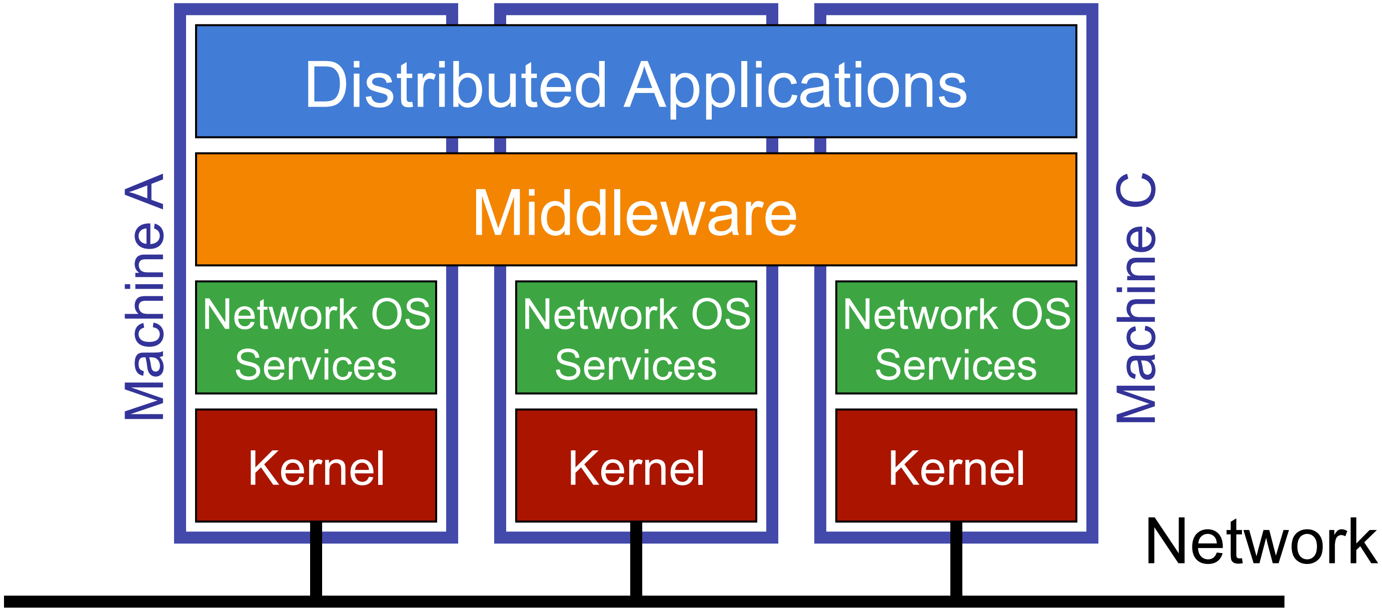
Consequences

- N **crash prone** machines **not** Turing complete

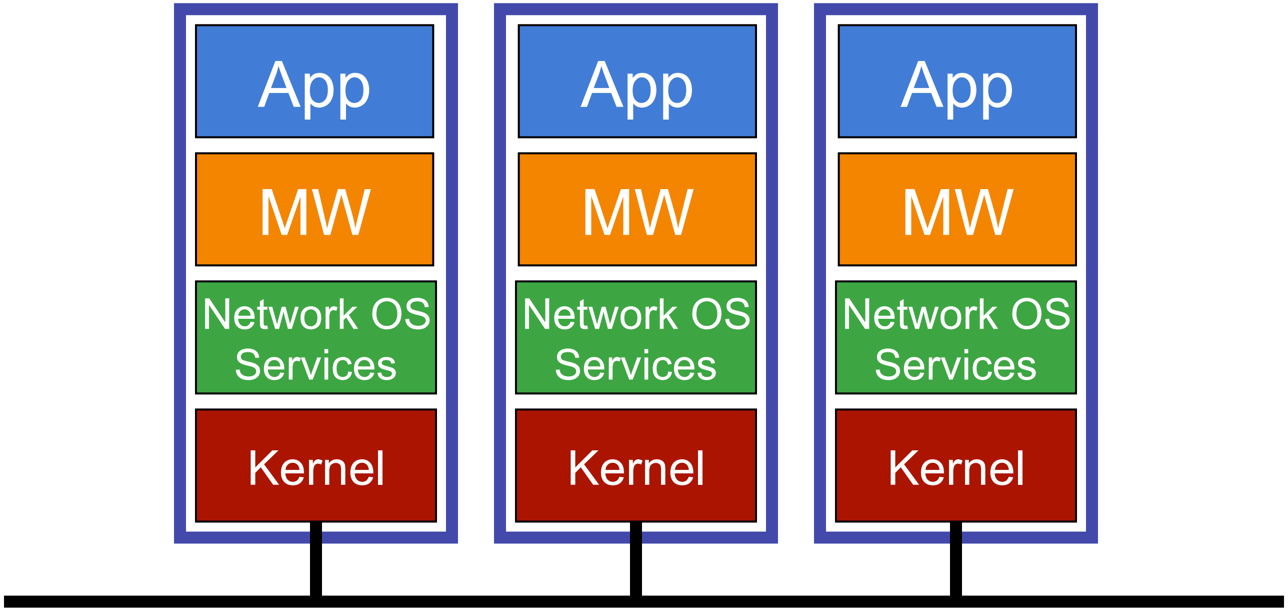
- Fischer, Michael J., Nancy A. Lynch, and Michael S. Paterson. "Impossibility of distributed consensus with one faulty process." *Journal of the ACM (JACM)* 32.2 (1985): 374-382.
- Gilbert, Seth, and Nancy Lynch. "Brewer's conjecture and the feasibility of consistent, available, partition-tolerant web services." *ACM SIGACT News* 33.2 (2002): 51-59.
- Herlihy, Maurice, Sergio Rajsbaum, and Michel Raynal. "Computability in distributed computing: a tutorial." *ACM SIGACT News* 43.3 (2012): 88-110.

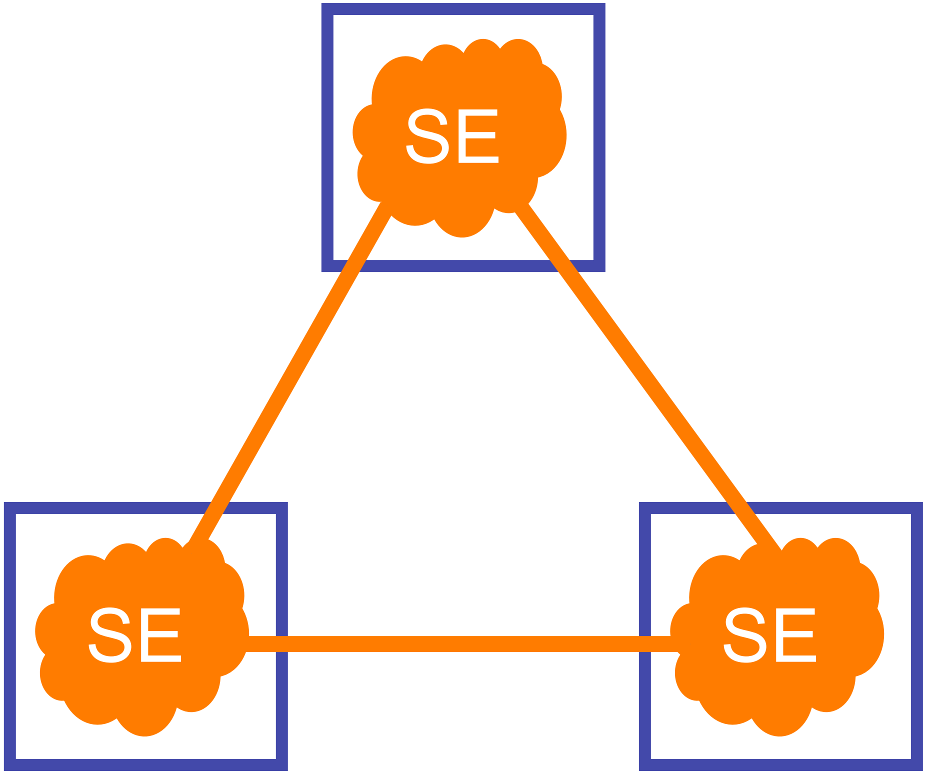
# Progress so far: Middleware

- Goal: **"nice"** programming abstractions
  - ➔ Challenge: to hide or not to hide distribution?



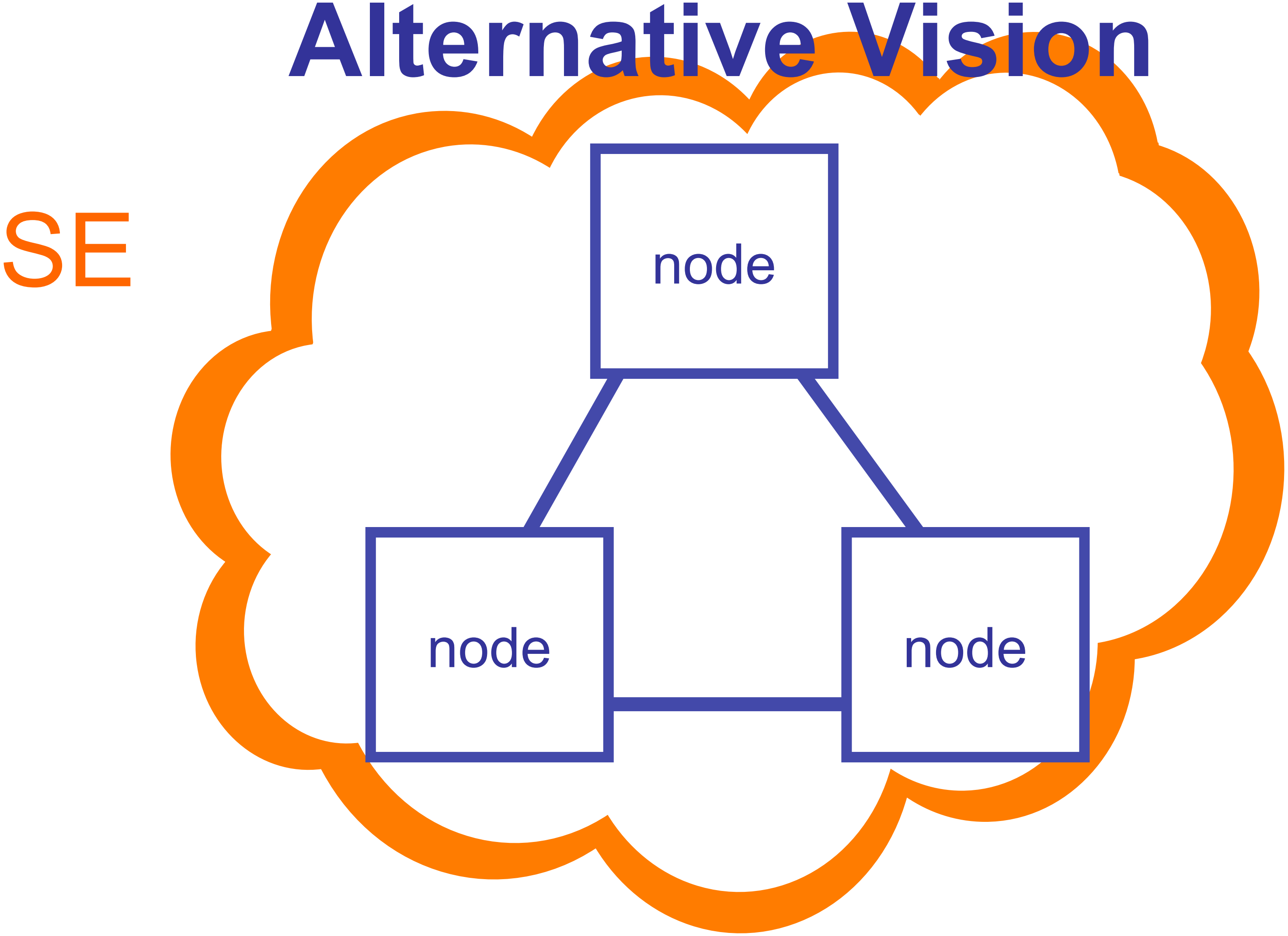
# In Practice


App
MW
Network OS Services
Kernel
App
MW
Network OS Services
Kernel
App
MW
Network OS Services
Kernel



Most of today's effort centred on programming **nodes**

# Alternative Vision



Tomorrow's systems will require a **holistic** approach.

# The Holistic Challenge

- (Strong) **consistency** is very **costly**
  - → The **one-entity** metaphor only goes so far.
- **Large scale**: embrace an **inconsistent** world
  - → Co-existence of past and present in the same system
  - → Partial adaptation
  - → Emerging behaviour
- **Challenges**
  - → Programming Models
  - → Interoperability
  - → Safety
  - → Security

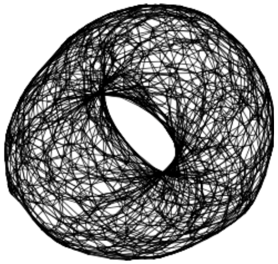
# Outline

- A call to arms: engineering large scale
- Examples of ways forward

# Example 1

**Dionasys** project (2014-2017)

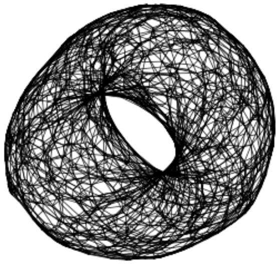
- Target
  - → **Large scale**, **heterogeneous** systems
  - → E.g. IoT + cloud + VANETs + mobiles
- Aim
  - → Principled **holistic** SE approach
- Tools
  - → **Self-stabilizing** overlays
  - → **Declarative** language
  - → **Components**



Jelasity et al [JMB09]

# Example 2

- Application of **components** + **DSL** to **gossip** protocols
  - ➔ Whisper + GossipKit

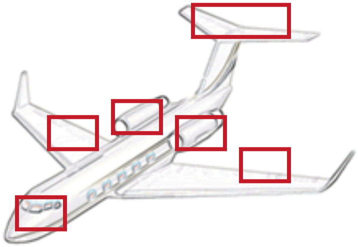


Jelasity et al [JMB09]

- Lin S., Taiani F., Bertier M., Blair G. S., Kermarrec A.-M. (2011). Transparent componentisation: high-level (re)configurable programming for evolving distributed systems. ACM SAC '11
- GossipKit: A Unified Component Framework for Gossip, François Taïani, Shen Lin, Gordon S. Blair, IEEE TSE, Feb. 2014

# Gossip Protocols

- Historical Distributed System
  - ➔ Deterministic with strong guarantees
  - ➔ Does not scale well



- Gossip (aka epidemic) Protocols
  - ➔ Introduce some '**chaos**'
  - ➔ Goal: system to **converge** to a desirable outcome
  - ➔ But some nodes might be left out

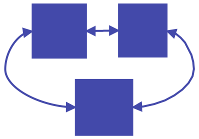
- Trading determinism for **scalability** & **robustness**

# Gossip Protocols (cont.)

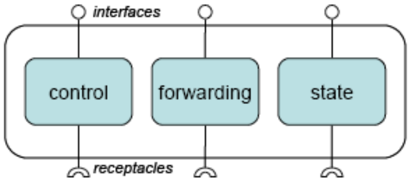
- Principles
  - ➔ leverage **rumour-like** propagation of information
  - ➔ large applicability: aggregation, broadcast, clustering
  - ➔ often **composed** to realised higher-level services
- Conceptually simple
  - ➔ typically symmetric behaviour
  - ➔ key notions of **state**, information **flows**, and **decisions**
- But implementation can be time consuming
  - ➔ multithreading, distributed coordination, network intricacies, co-existence

# Applying Components to Gossip

- Component successfully applied to distributed systems
  - ➔ industry: EJB, CCM, OSGi, SCA
  - ➔ research: Fractal, OpenCOM, FraSCAti
  - ➔ middleware Frameworks: GridKit, Rapidware, Ensemble, Cactus, Open Overlays

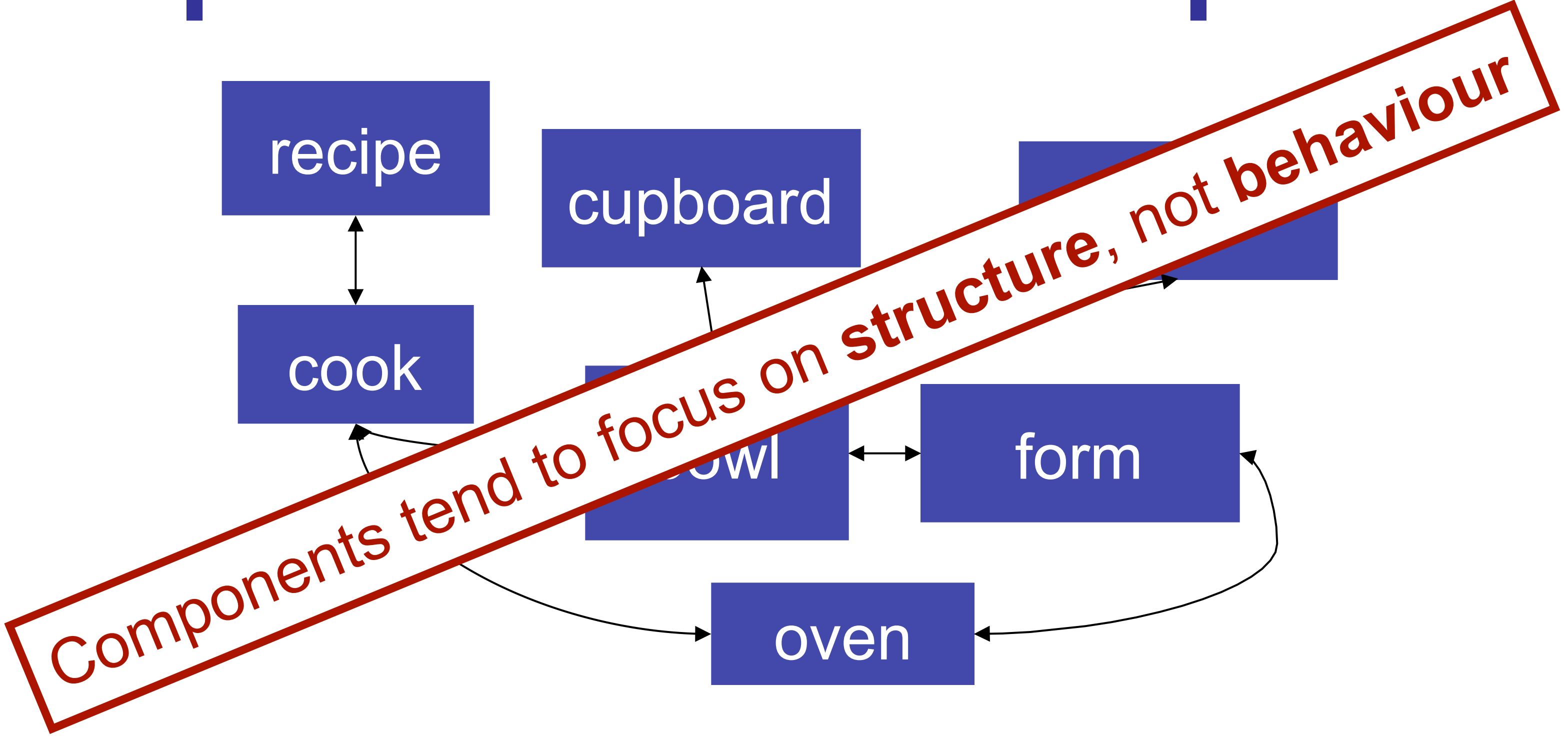


- Clear **structure**, explicit **dependencies**



- Benefits
  - ☺ promote **reuse**
  - ☺ easily **composable** and **configurable** (SPL..)
  - ☺ lend themselves to **runtime reconfiguration**

# The problem with components



Components tend to focus on **structure**, not **behaviour**

- Drawbacks
  - ☹ low **intelligibility** (where is the intent?)
  - ☹ conceptual **mismatch** for developers focusing on behaviour
  - ☹ high **learning** curve for unfamiliar frameworks

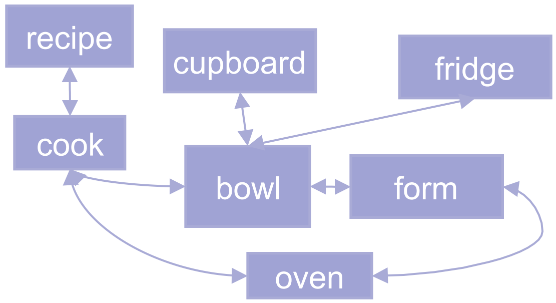
# Applying SDL to Gossip

- **Spec. lang. and DSL:** High-level per node description
  - ➔ Lotos, Estelle, PLAN-P, Mace …

bake

- **Macro-programming**: system as one entity
  - ➔ E.g. Kairos, Regiment, TinyDB, MIT-Proto
  - ➔ centralised shared-memory parallel abstraction
  - ➔ main program compiled into code for each node
- Benefits
  - ☺ high level of **abstraction** (in particular for macro-prog)
  - ☺ **intelligible**
  - ☺ good conceptual **match** for developers looking at behaviour

# Behaviour rather than structure



recipe

cupboard

fridge

cook

bowl

form

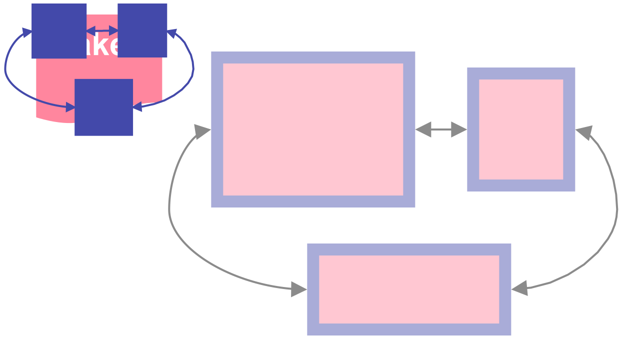
oven

```
add(yohourt,1)
add(milk,2)
add(flour,3)
add(butter,1)
bowl.pour(form)
form.putln(oven)
bake()
```

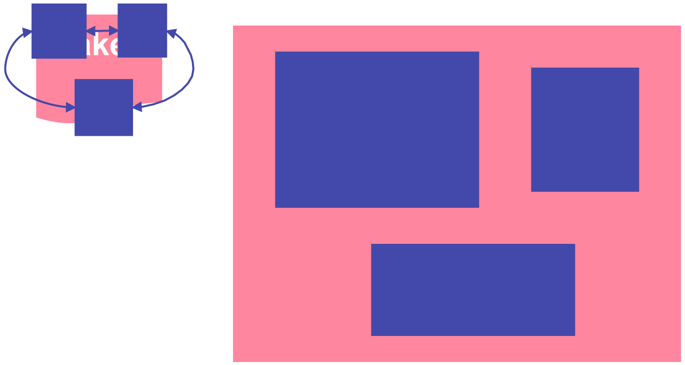
**Can we build a hybrid approach that combines the strengths of components & high-level languages?**

- Drawbacks
  - ☹ we loose the benefits of components (reuse, adaptation, …)

# structure + behaviour = ?



encapsulation

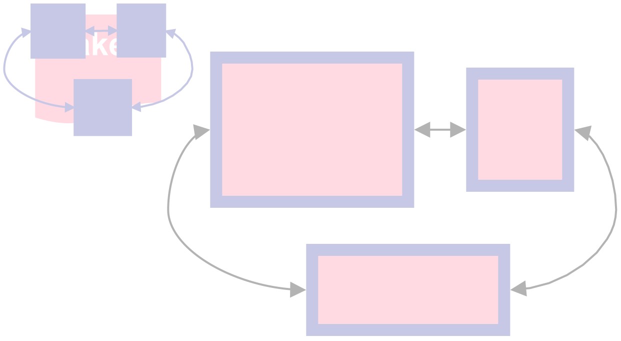


orchestration

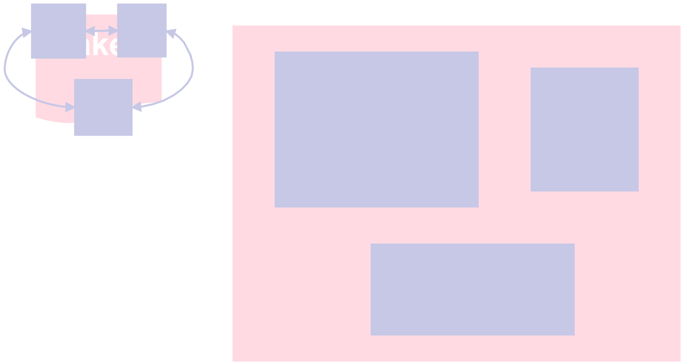
- 😐 **tangling** behaviour & structure
- 😐 ‘breaks’ **encapsulation**
- 😐 tension **flexibility** vs. **scattering**

- 😐 **complex** composition
- 😐 tension **structural** needs vs. **programmatic** ones

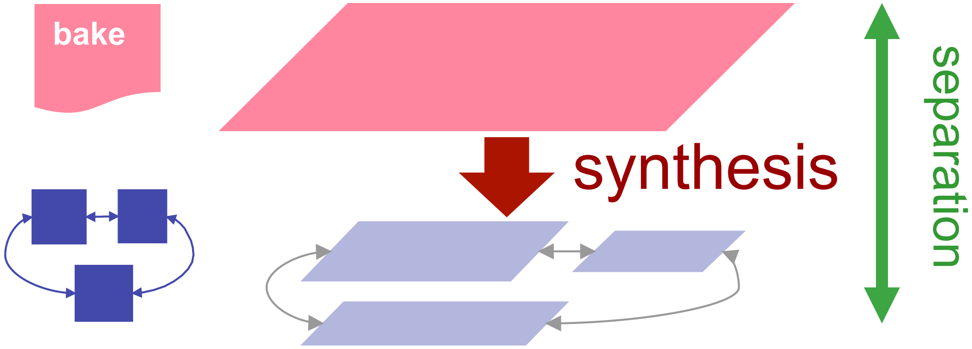
# structure + behaviour = ?



encapsulation

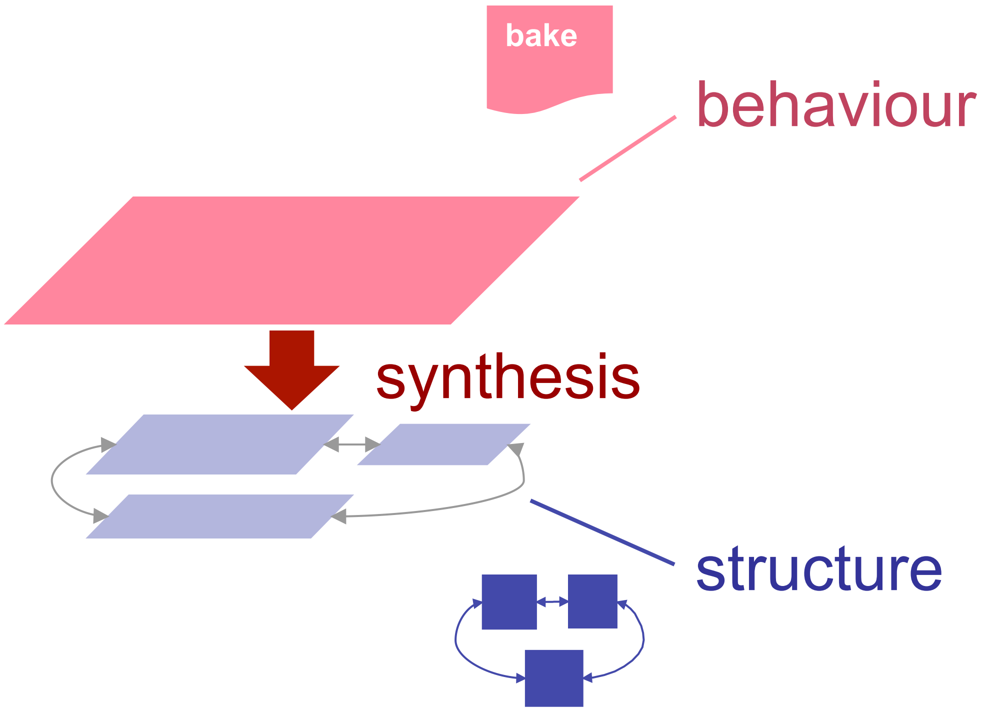


orchestration



**transparent componentisation**

# Transparent Componentisation

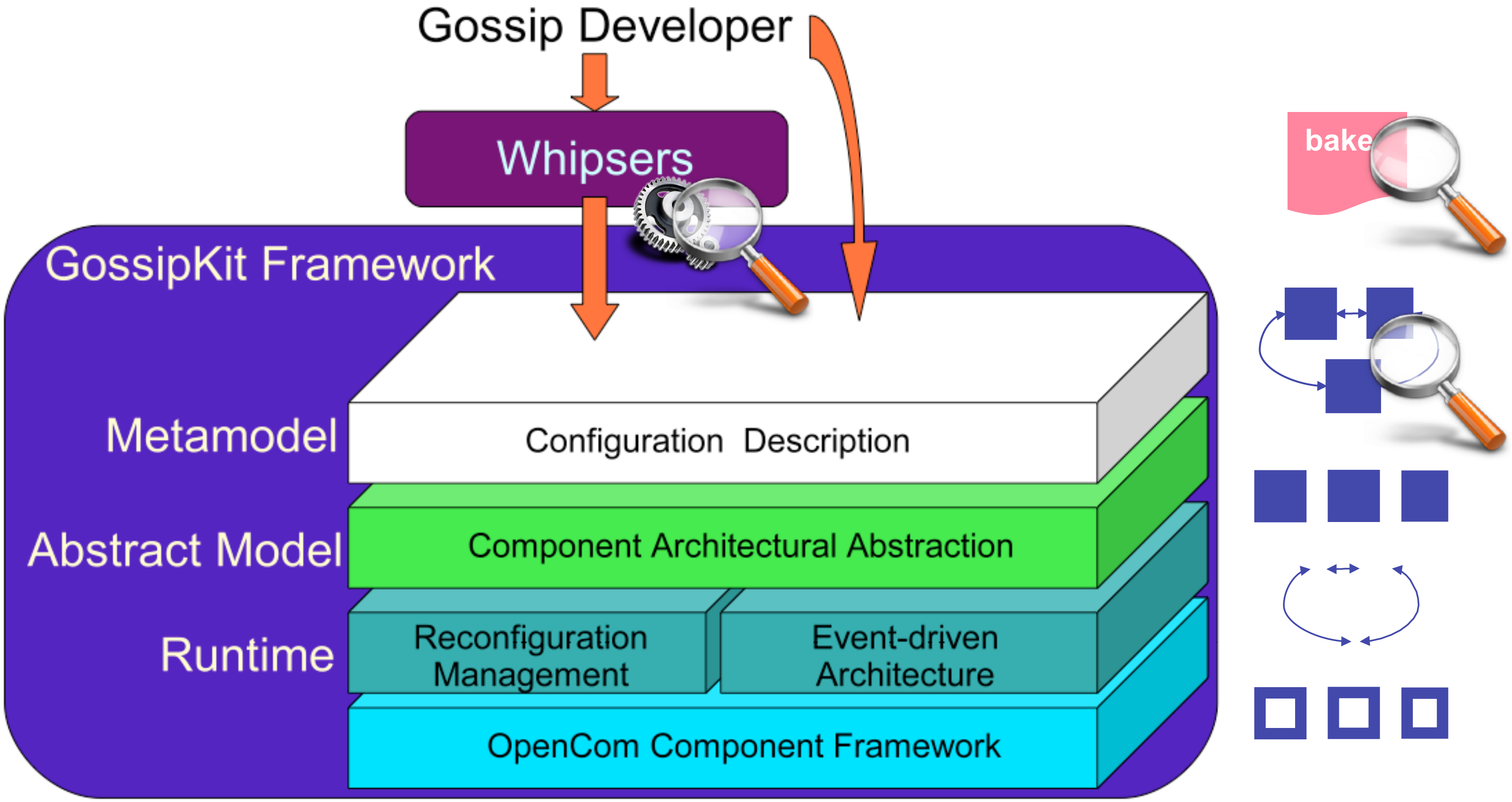


☺ simple
☺ concise
☺ high-level

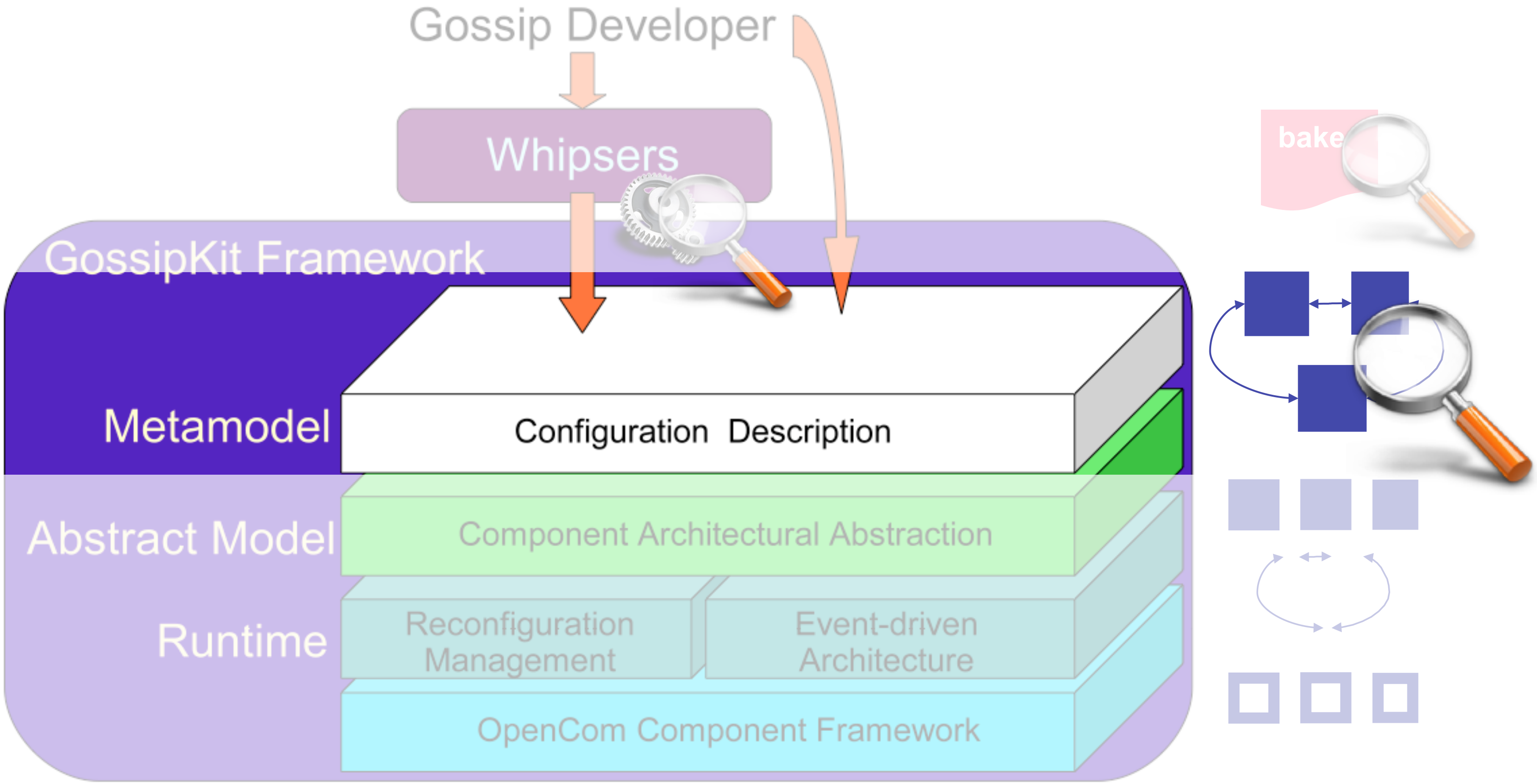
☺ modular
☺ reusable
☺ (re)configurable

- **Separation of concern** between behaviour / structure
- **Developers** can focus on **high level logic**
- **Systems** takes care of **modularity**, reuse, and evolution

# The WhispersKit Architecture


Gossip Developer
Whipsers
GossipKit Framework
Metamodel
Configuration Description
Abstract Model
Component Architectural Abstraction
Runtime
Reconfiguration Management
Event-driven Architecture
OpenCom Component Framework
bake

# The WhispersKit Architecture



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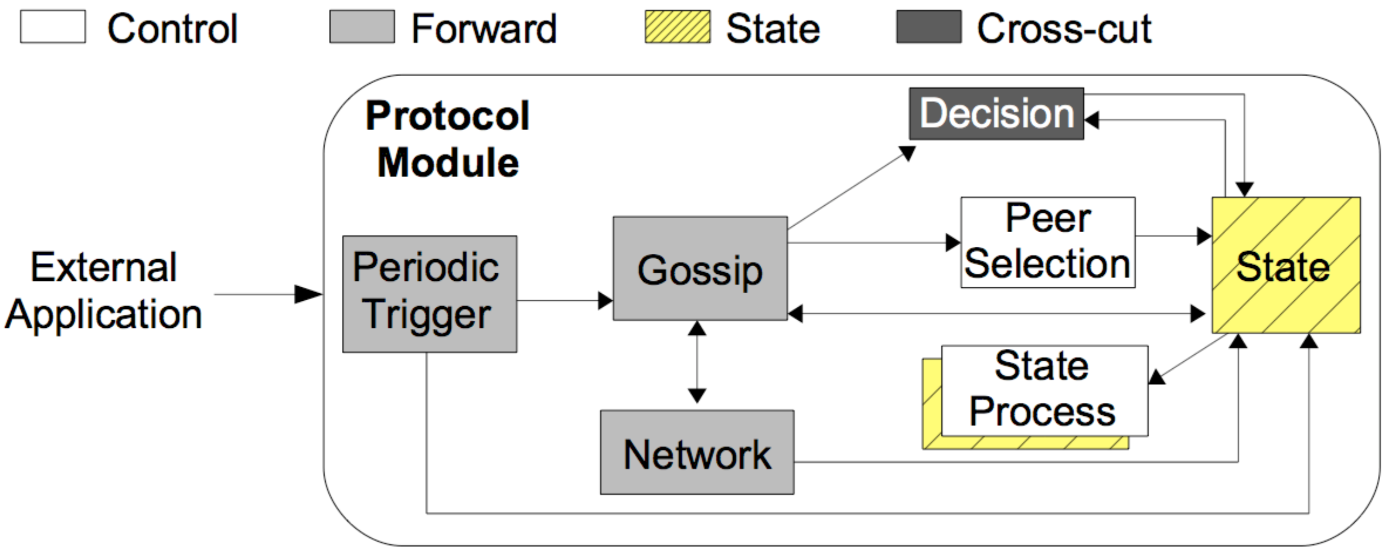
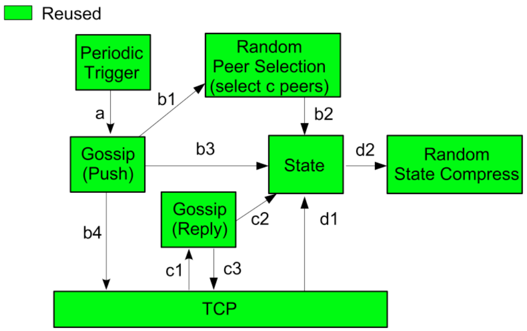
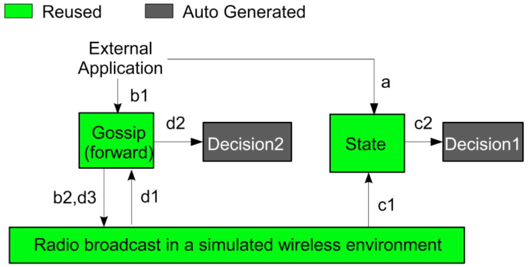


- A component **framework** for **epidemic** protocols
  - ➔ based on analysis of 30 gossip protocols
  - ➔ **event-based**
  - ➔ XML-based **configuration** for component composition
  - ➔ targets abstraction, modularity, reuse, evolvability

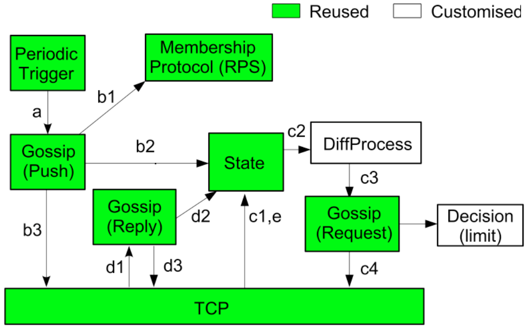
# GossipKit Examples



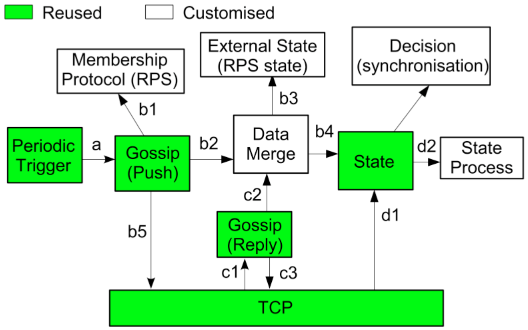
RPS



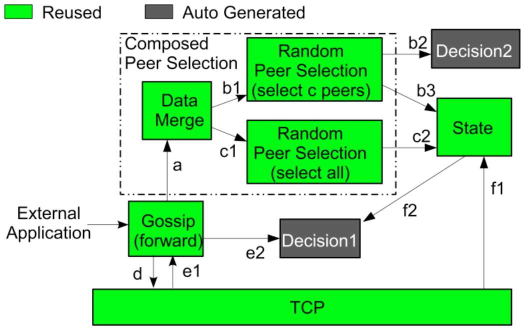
Wireless broadcast



Anti-Entropy

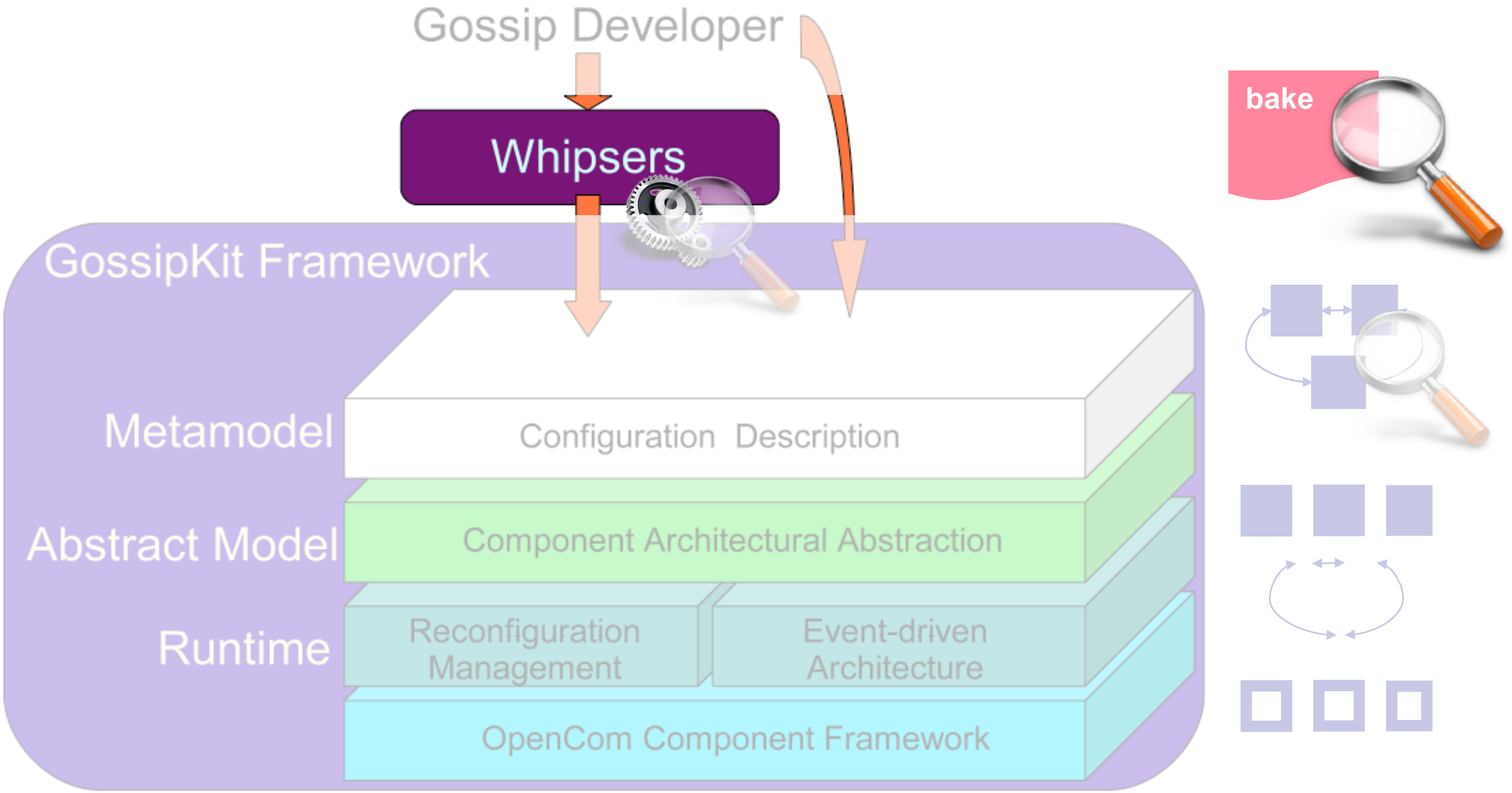


T-Man



SCAMP

# The WhispersKit Architecture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# Whispers

- macro-programming language for gossip protocols
  - ➔ system as one entity
- primitives

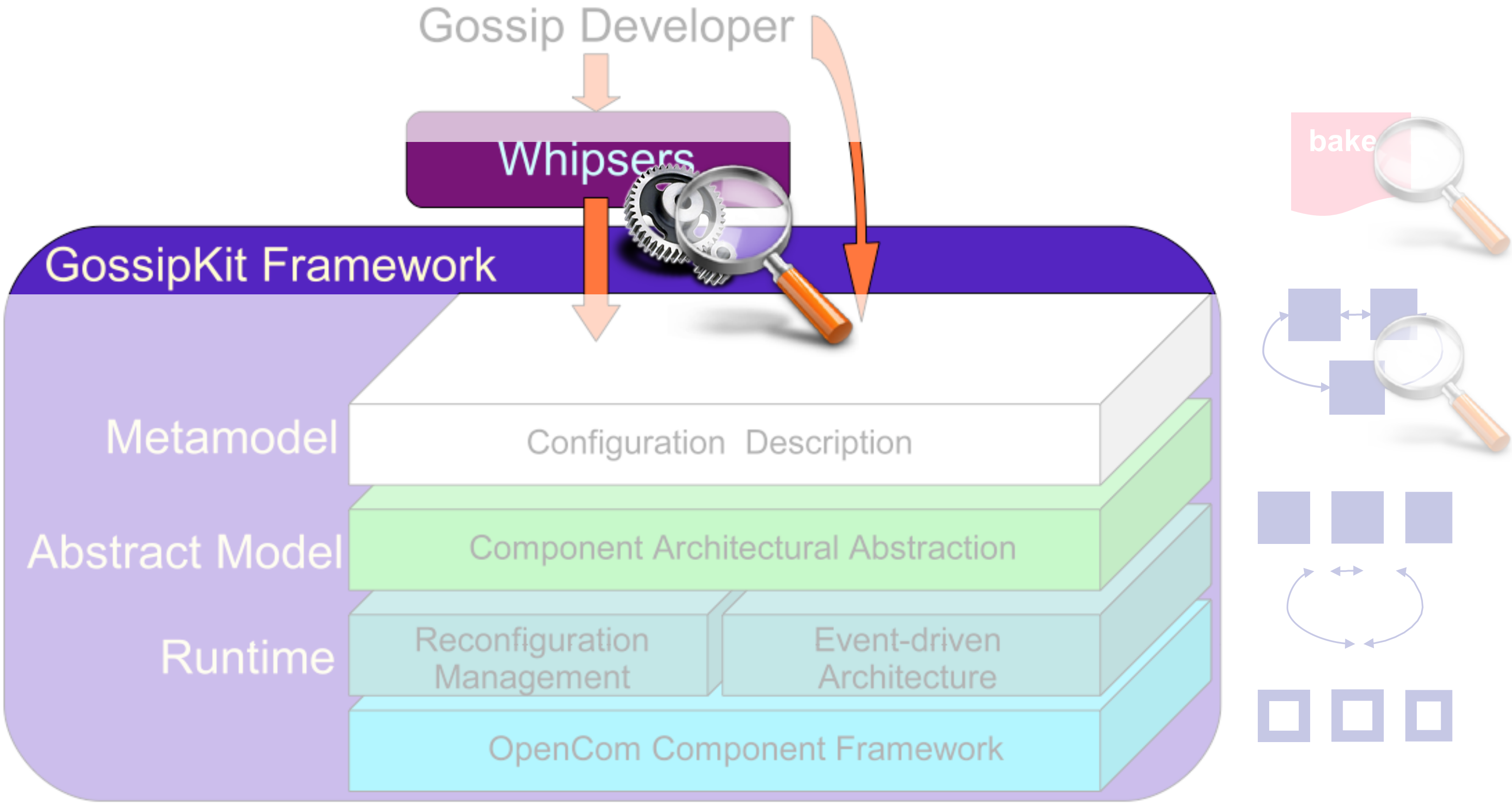
```
protocol {..}              // protocol block
every (time) {..}          // periodic behaviours
wait (Event e type T) {..} // reactive behaviours
foreach(n in nodeSet)      // distribution
synchronised {..}          // pairwise data exchange
State state = new State[fields][size] ; // state decl.
state.field ;              // get a column of data
state.add([fields])        // add
state.remove(row_ID)       // remove
i.RandomStateCompress(...) // library call
```

# Whispers Example: RPS

```
RPS {
  State sample = new State[Node:PeerID][Size=5];
  Node n, i;
  every (5000) { // do the following every 5000 ms
    foreach (n in AllNodes) { // for each node n
      i=n.RandomPeerSelection(n.sample)[Size=1];
      n.sample.add([n]);
      i.RandomStateCompress(i.sample,n.sample)[Size=5];
      n.RandomStateCompress(i.sample,n.sample)[Size=5];
    } // end of foreach
  } // end of every
} // end of RPS protocol block
```

Jelasity, M., Guerraoui, R., Kermarrec, A.-M., and van Steen, M. (2004). The peer sampling service: experimental evaluation of unstructured gossip-based implementations. Middleware ’04

# The WhispersKit Architecture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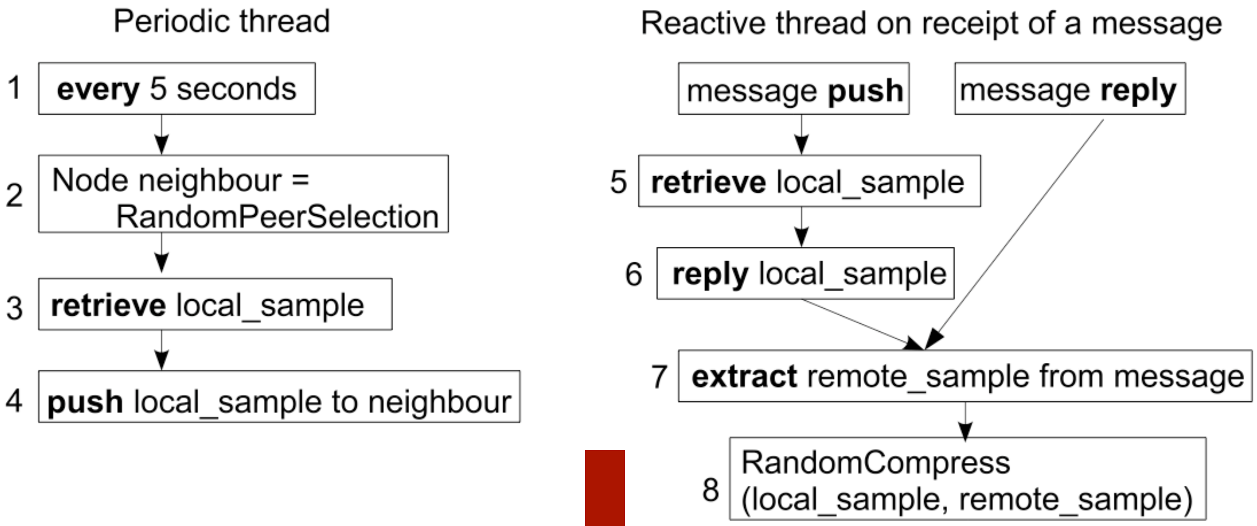
# Compilation

```
RPS {
  State sample = new State[Node:PeerID][Size=5];
  Node n, i;
  every (5000) { // do the following every 5000 ms
    foreach (n in AllNodes) { // for each node n
      i=n.RandomPeerSelection(n.sample)[Size=1];
      n.sample.add([n]);
      i.RandomStateCompress(i.sa
      n.RandomStateCompress(i.sa
    } // end of foreach
  } // end of every
} // end of RPS protocol block
```

bake



Periodic thread

1 **every** 5 seconds

2 Node neighbour = RandomPeerSelection

3 **retrieve** local_sample

4 **push** local_sample to neighbour

Reactive thread on receipt of a message

message **push**

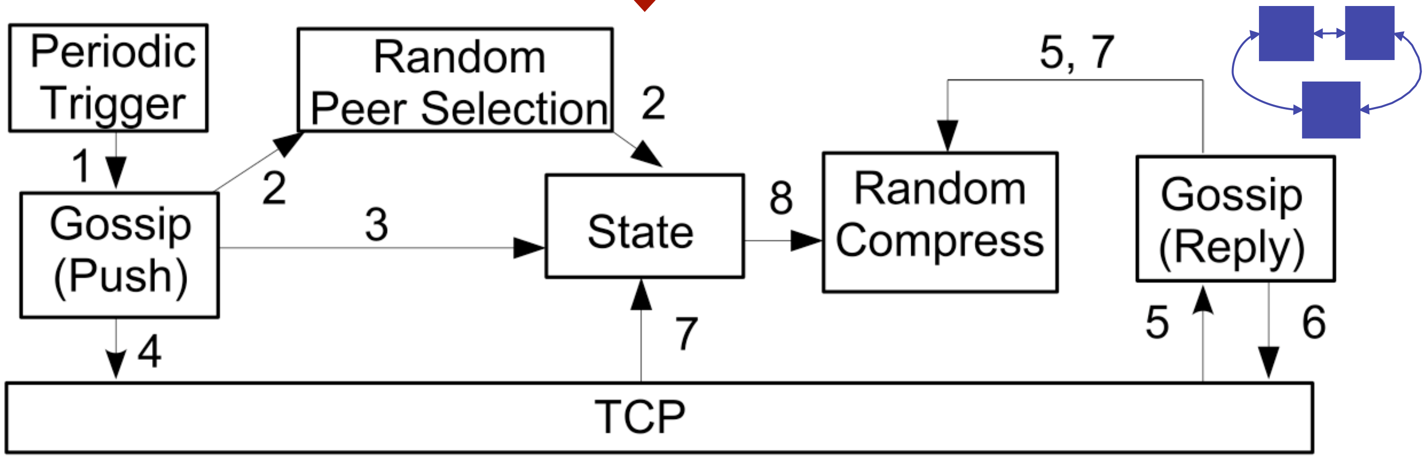
message **reply**

5 **retrieve** local_sample

6 **reply** local_sample

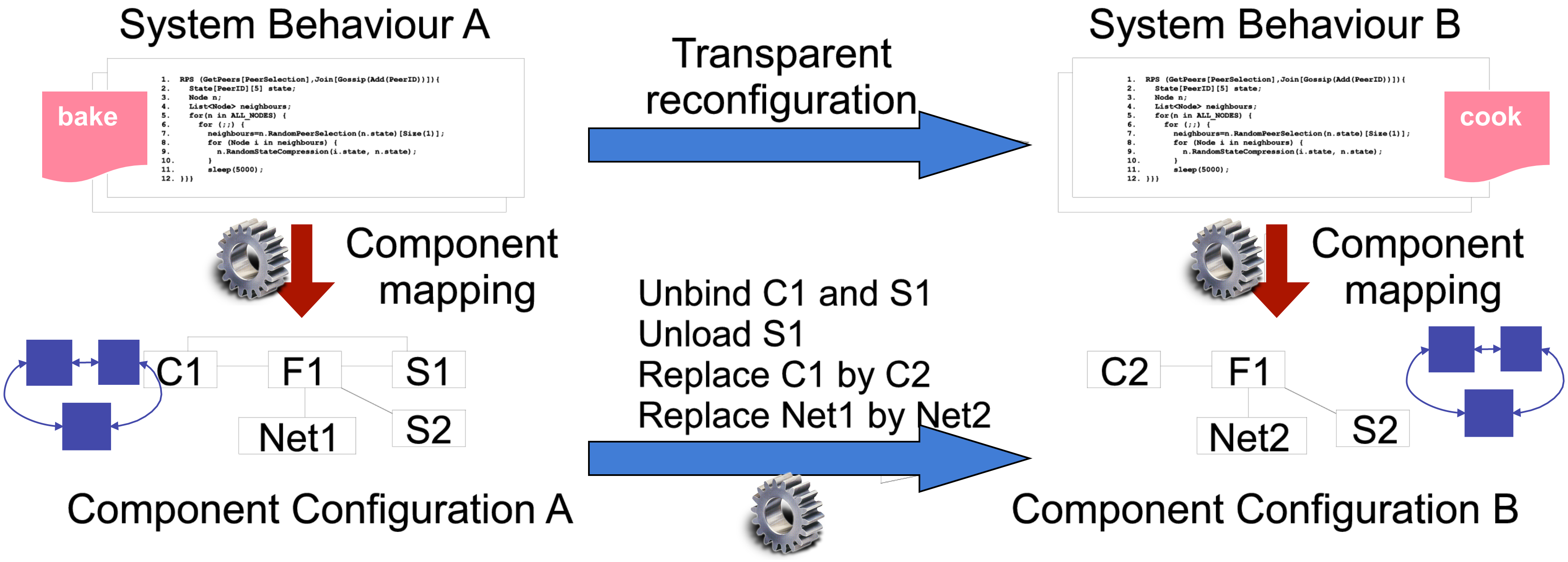
7 **extract** remote_sample from message

8 RandomCompress (local_sample, remote_sample)



# Distributed Reconfiguration

- A developer describes new behaviour in Whispers.
- The platform uses component representation
  - ➔ to compute minimal set of changes;
  - ➔ to propagate and enact reconfiguration.



System Behaviour A

bake

```
RPS (GetPeers[PeerSelection],Join[Gossip(Add(PeerID))]){
  State[PeerID][5] state;
  Node n;
  List<Node> neighbours;
  for(n in ALL_NODES) {
    for (;;) {
      neighbours=n.RandomPeerSelection(n.state)[Size(1)];
      for (Node i in neighbours) {
        n.RandomStateCompression(i.state, n.state);
      }
      sleep(5000);
}}}
```

Transparent reconfiguration

System Behaviour B

cook

```
RPS (GetPeers[PeerSelection],Join[Gossip(Add(PeerID))]){
  State[PeerID][5] state;
  Node n;
  List<Node> neighbours;
  for(n in ALL_NODES) {
    for (;;) {
      neighbours=n.RandomPeerSelection(n.state)[Size(1)];
      for (Node i in neighbours) {
        n.RandomStateCompression(i.state, n.state);
      }
      sleep(5000);
}}}
```

Component mapping

Component mapping

Unbind C1 and S1
Unload S1
Replace C1 by C2
Replace Net1 by Net2

Component Configuration A

Component Configuration B

# Distributed Reconfiguration

- Example: RPS → T-Simple (Ring) → T-Simple (Grid)

*coarse grained*

*fine grained*

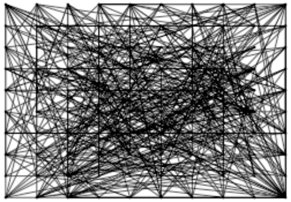


Figure 5.6: Initial random graph maintained by RPS

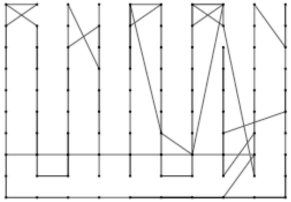


Figure 5.7: 5th rounds since 1st reconfiguration

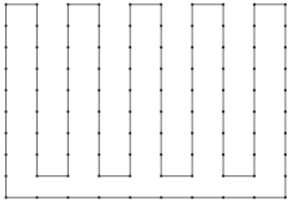


Figure 5.8: Ring constructed at the 11th round

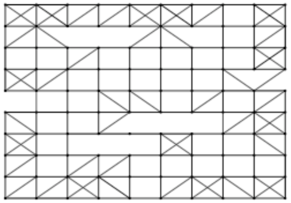


Figure 5.9: Topology at the 20th round

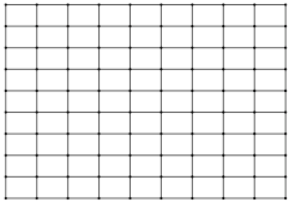


Figure 5.10: Grid constructed at the 23rd round

# Conclusion

- The world is **distributed**, the world is **large**

- **Distribution** is more than concatenation
  - ➔ **Failures** and **uncertainties**
- **Large-scale** distributed systems even more so
  - ➔ **Information** takes **time** to travel

- Novel **software engineering** approaches needed
  - ➔ Away from node-centric view
  - ➔ Holistic yet loosely coupled approaches ideal

# Thank you

# Task Failures at Google

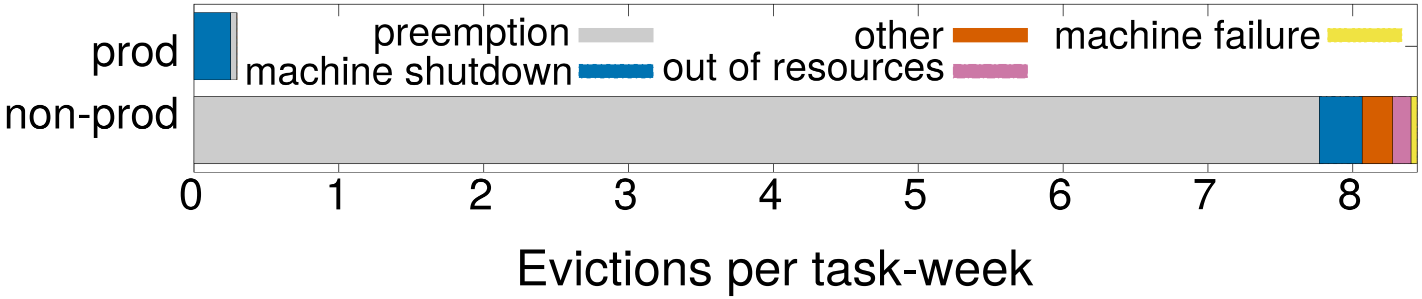


**Figure 3:** Task-eviction rates and causes for production and non-production workloads. *Data from August 1st 2013.*

- Source: Large-scale cluster management at Google with Borg
  Abhishek Verma, Luis Pedrosa, Madhukar R. Korupolu, David Oppenheimer, Eric Tune, John Wilkes
  EuroSys'2015, Bordeaux, France (2015)

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