Software Challenges and Solutions for Ad Hoc Networks

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Fonds national suisse
Swiss National Science Foundation

The National Centres of Competence in Research are managed by the
Swiss National Science Foundation on behalf of the Federal Authorities

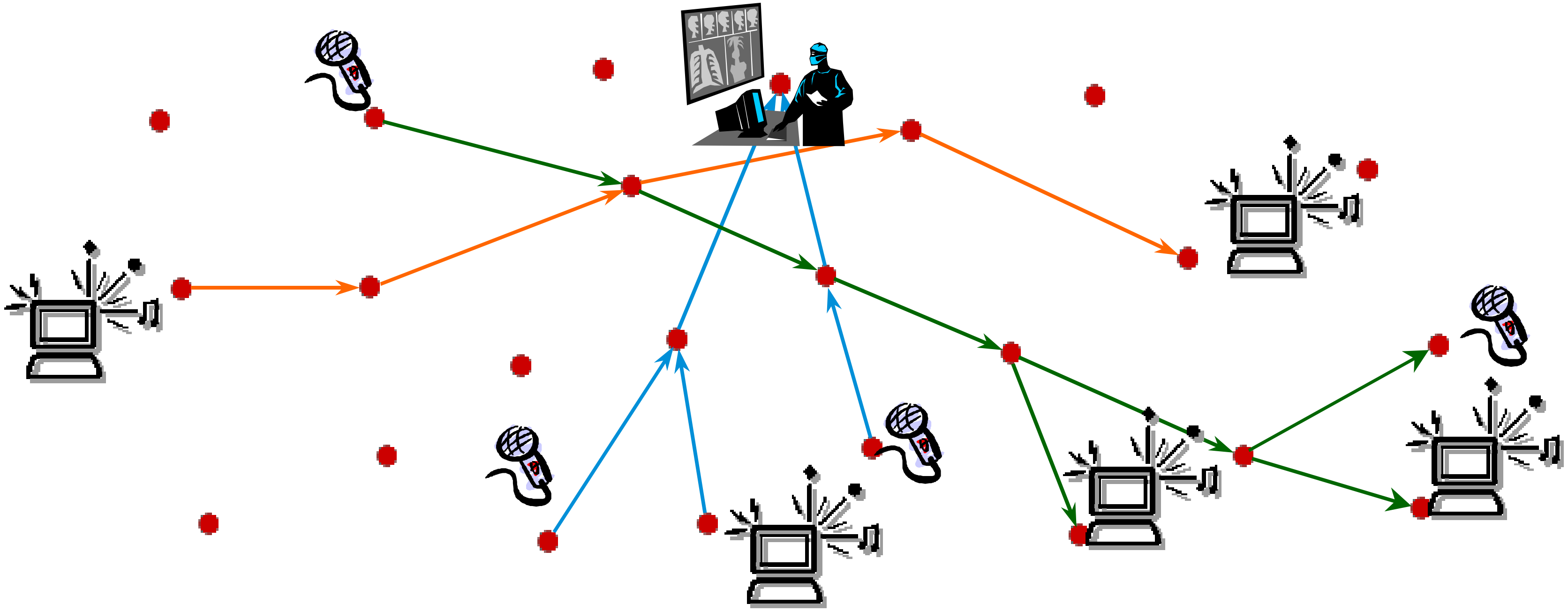
Outline

- Ad hoc networks
- Software challenges
- How to address (some) challenges
  - Structures (research community)
  - Flexibility (software system design)
- Concluding remarks

Ad hoc networks

- Basic idea: network without “managed” infrastructure
  - An idea as old as networks
  - Infrastructure can break

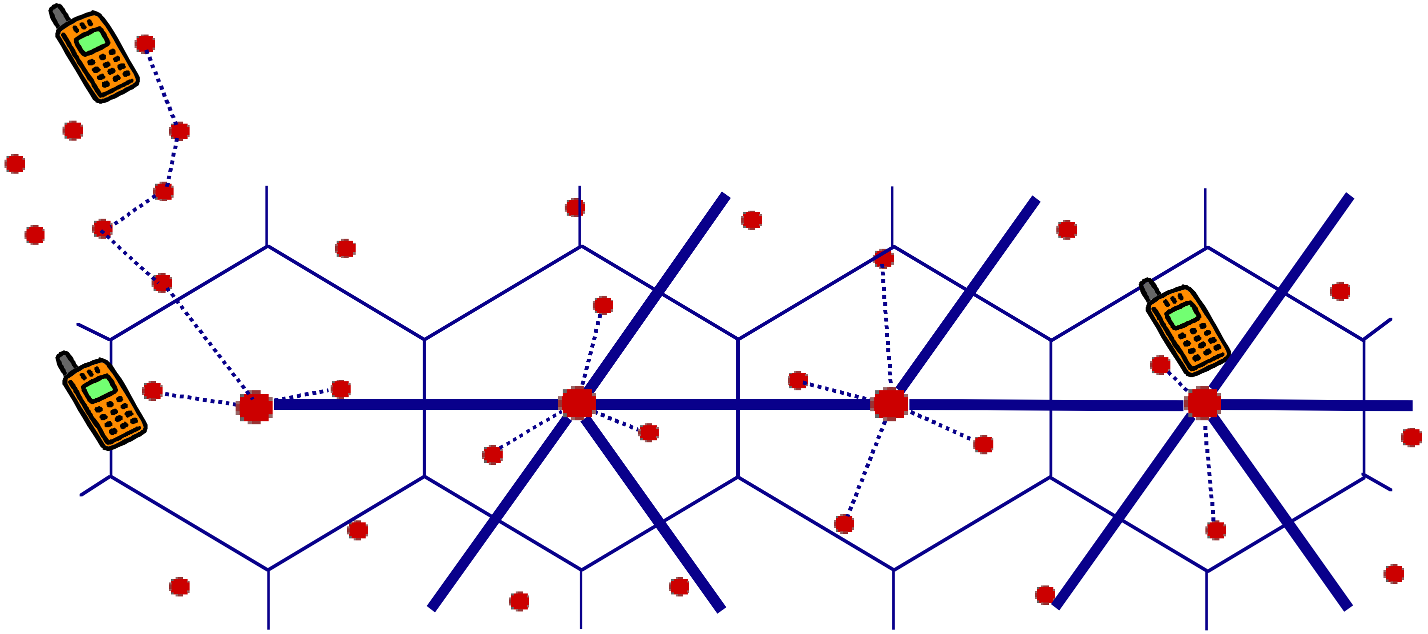
Artist’s rendition



Ad hoc networks (2)

- Managed infrastructure has its advantages
  - A Jazz ensemble may get by without a conductor
  - But the audience still has to agree to be quiet.
- Ad hoc networks on the “fringe” of the wire-based (managed) infrastructure
  - Co-exist

Artist’s view (2)



Some problems

- Design of antennas and air interfaces
- Coordination of devices
- Protocol services
- Charging and fairness
- Security
- Privacy and public safety
- Application properties

Where is there software?

- Design of antennas and air interfaces
  - Software radios
- Coordination of devices
  - Distributed coordination
- Protocol services
  - Routing
- Charging and fairness
- Security
- Privacy and public safety
- Application properties

Ad hoc networks (3)

- Some issues/questions:
  - What are the “nodes”?
    - Capabilities
    - Latencies
    - Programming model
    - Physical constraints
    - Usage patterns
    - Government regulations and user perceptions
  - Launch into established, high-barrier-to-entry markets not a good idea
    - Even a sick 800 pound gorilla not easily moved
    - Plus: if the gorilla got sick, why do you want its cell?
- What applications are *enabled* by ad hoc networks?

Two endpoints

- Sensor nets
  - A hot topic
  - Environmental monitoring more important

- Application in self-organizing environments
  - Information systems as a model for applications
  - Large body of practical experience with heterogeneous environments and networks

Fighting isolationism

- The limitations of the “individual investigator” model make progress on *cross-area* issues difficult.
  - Combine constraints of multiple layers/areas
- Need to form teams
  - Done on many US institutions
  - Old mode of operation for mission-oriented funding agencies
  - Not usually done in universities in the Humboldt tradition
    - A “chair” covers an area/topic
  - (Virtual) research networks offer an alternative
    - Want to include all players, regardless of location

MICS: Mobile Information and Communication Systems

- A project funded by the Swiss National Science Foundation (SNF)
  - NCCR: National Center of Competence in Research
- NCCR: Swiss incarnation of a US NSF “Engineering Research Center“ (ERC)

What is an NCCR?

- Goals (of the Swiss National Science Foundation):
  - "Promotion of scientific excellence in areas of major strategic importance for Switzerland"
  - Re-shaping of the Swiss academic landscape, by getting the institutions to define priorities and to network with one another
- Currently 14 NCCRs
  - life sciences (5)
  - physics (3)
  - information technologies (3)
  - sustainable development and environment (2), social and human sciences (1)

What is an NCCR?

- Project horizon 10 years, funding allocated for 4 years (Nov 2005)
  - Organized as “network of individual projects (IP)“
- MICS budget: CHF 32M (US$ 20M) over 4 years
  - 50% SNF, 50% matching by home institution
- MICS size: about 30 faculty members and 60-70 PhD students
- MICS operation: officially started on Nov 1st 2001
  - For most groups: now in operation for one year

What is an NCCR?

- Goals (of the researchers):
  - Have fun.
  - Engage in good research. Write papers.
  - Pay doctoral students.
  - ..... (some are probably not disclosed)
  - Work with other experts.

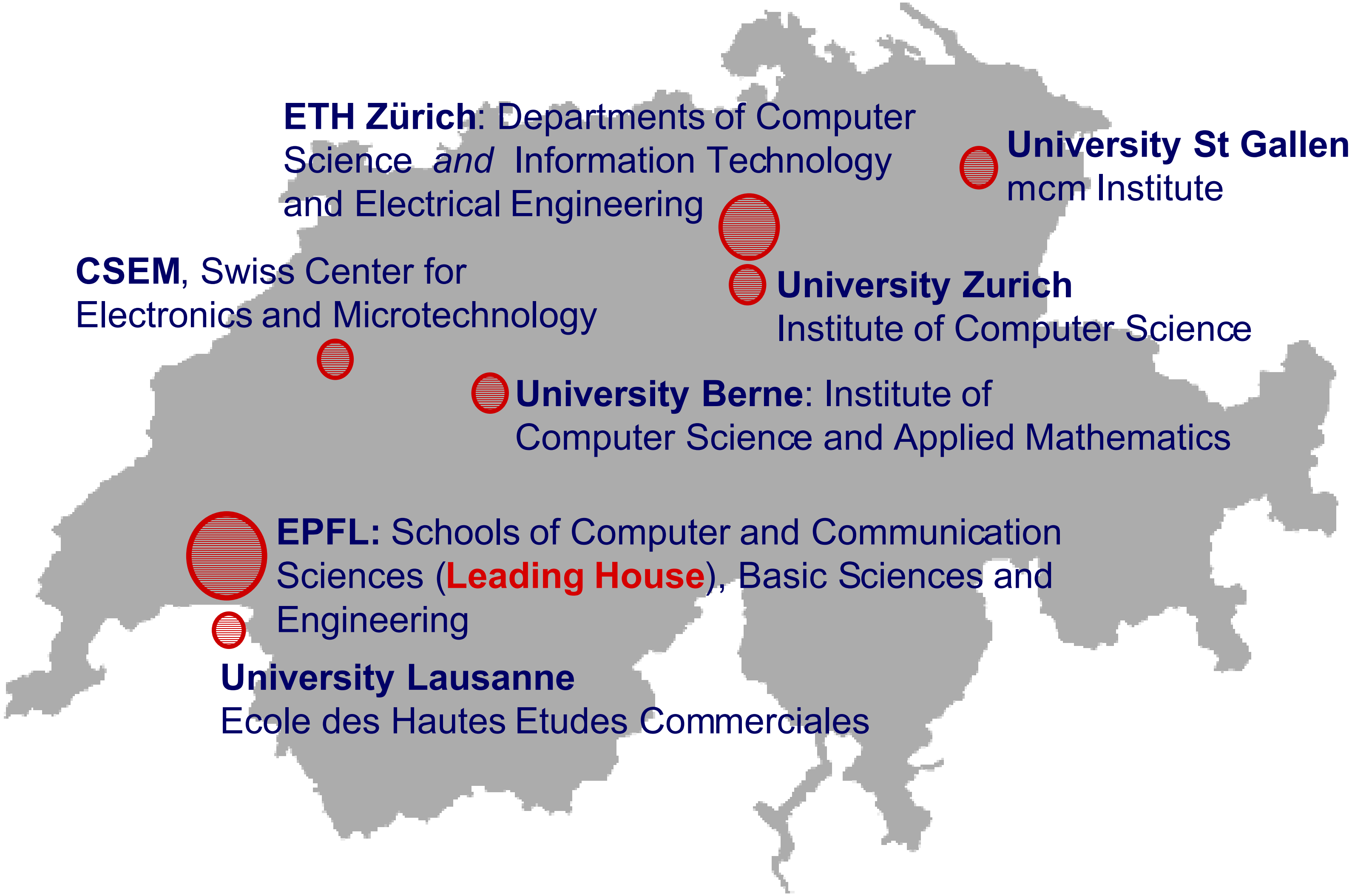
MICS

- MICS organized into
  - Leading house (EPF Lausanne)
    - Director M. Vetterli
    - Administration and accounting
  - Management team (committee)
    - Representatives of IPs
    - Director/Deputy Director
  - 11 individual projects (“IP”)
    - Researchers from various Swiss institutions

NCCR MICS (self) organization

- Mathematics of self-organized communications, P.Thiran (EPFL)
- Information theoretic issues, E. Telatar (EPFL)
- Physical layer and software radio testbed, B. Rimoldi (EPFL)
- Self-organizing networking mechanisms, J.-P. Hubaux (EPFL)
- Self-organized distributed applications in a mobile environment, K. Aberer (EPFL)
- Security and cryptographic issues, S. Vaudenay (EPFL)
- Distributed signal processing and communication, M. Vetterli (EPFL)
- System and software architecture, T. Gross (ETHZ)
- Communicating embedded systems, L. Thiele (ETHZ)
- Terminodes, wireless e-business models and scenario planning, Y. Pigneur (UNIL)
- Wireless sensor networks, C. Enz (CSEM)

Projects are distributed



ETH Zürich: Departments of Computer Science *and* Information Technology and Electrical Engineering

University St Gallen
mcm Institute

CSEM, Swiss Center for Electronics and Microtechnology

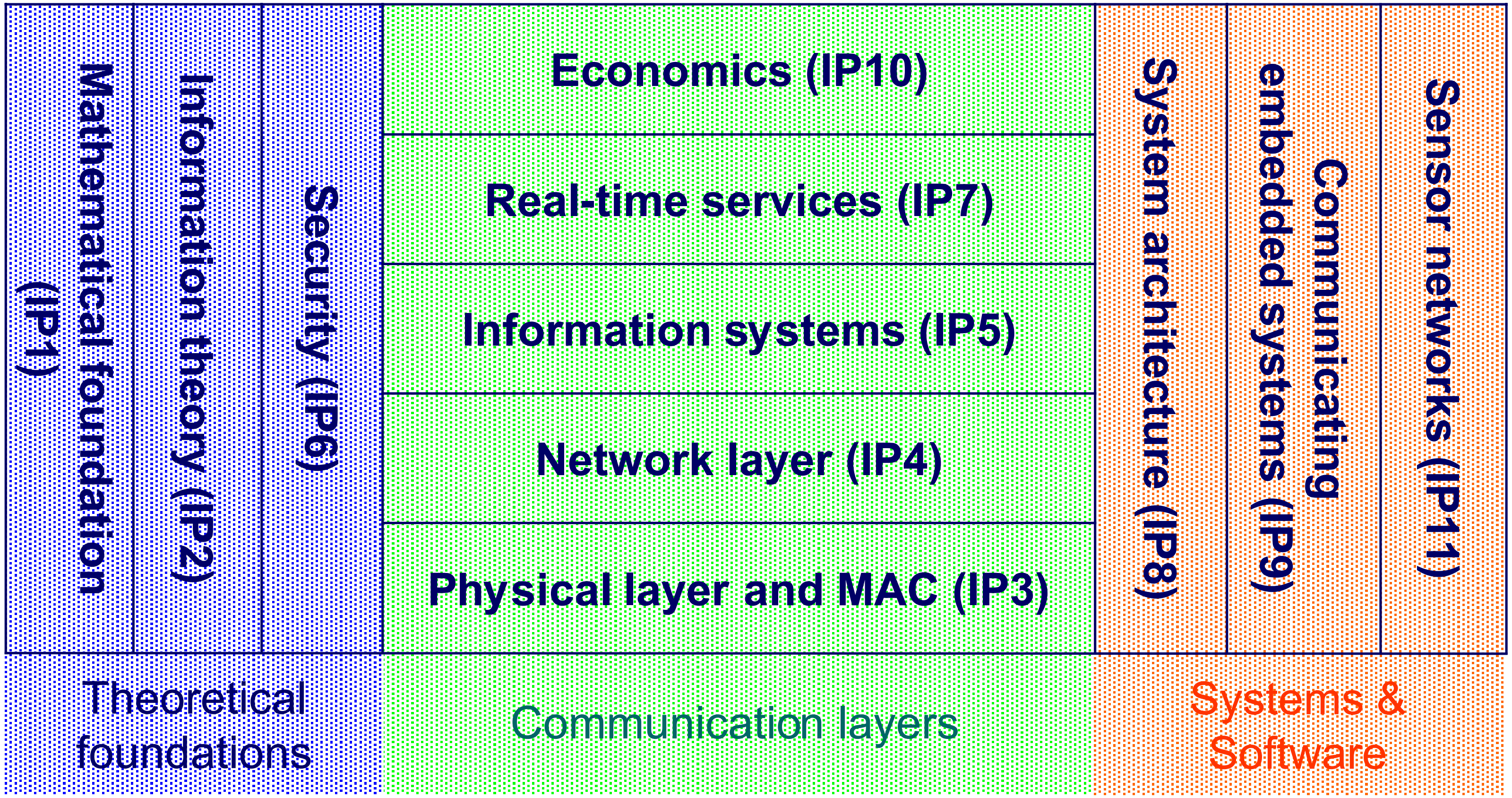
University Zurich
Institute of Computer Science

University Berne: Institute of Computer Science and Applied Mathematics

EPFL: Schools of Computer and Communication Sciences (**Leading House**), Basic Sciences and Engineering

University Lausanne
Ecole des Hautes Etudes Commerciales

Working across layers



Mathematical foundation (IP1)

Information theory (IP2)

Security (IP6)

Economics (IP10)

Real-time services (IP7)

Information systems (IP5)

Network layer (IP4)

Physical layer and MAC (IP3)

System architecture (IP8)

Communicating embedded systems (IP9)

Sensor networks (IP11)

Theoretical foundations

Communication layers

Systems & Software

Other activities

- Protoype systems
  - Sensor networks -- what sensors?
    - Environmental monitoring
    - Intelligent buildings
- Industrial liason program
- Summer intern program for undergraduates
- Community building for women researchers
- Doctoral summer school
  - If you [or your students] are interested ...

    www.nccr-mics.ch

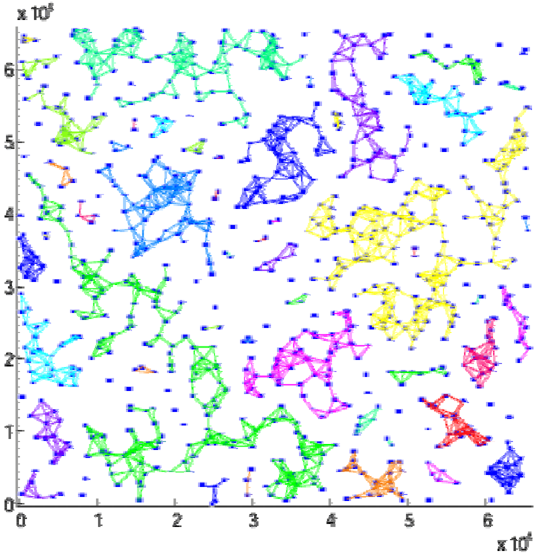
Cross-layer and cross-cultural collaboration

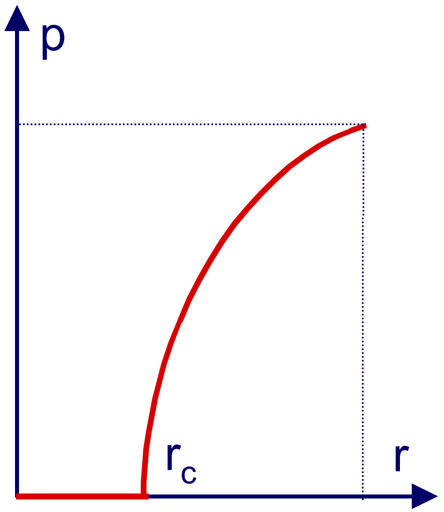
- Connectivity in large-scale networks
- Mobility and routing
- Adaptive software systems

Connectivity of large-scale networks

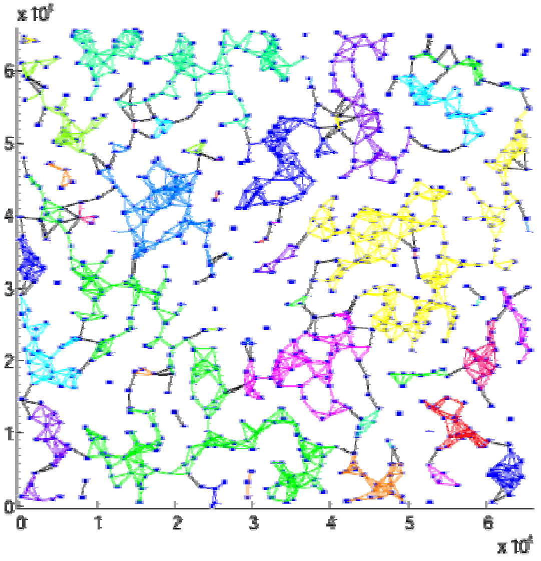
- **P. Thiran, O. Dousse, EPFL, IP1**
- **Phase transition phenomenon**
  - **Below a critical power r_c -> disconnected network**
  - **Above critical power r_c -> rapidly increasing probability p of connected network**

sub-critical (r slightly < r_c)





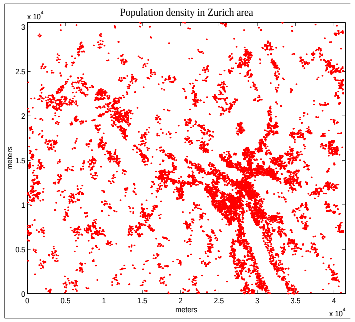
super-critical (r slightly > r_c)



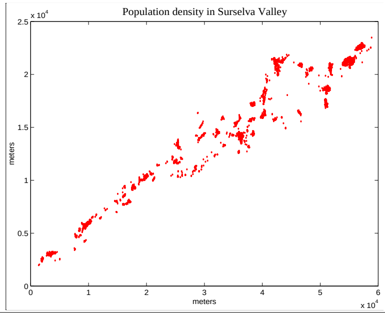
Connectivity of large-scale networks

Why would you care?

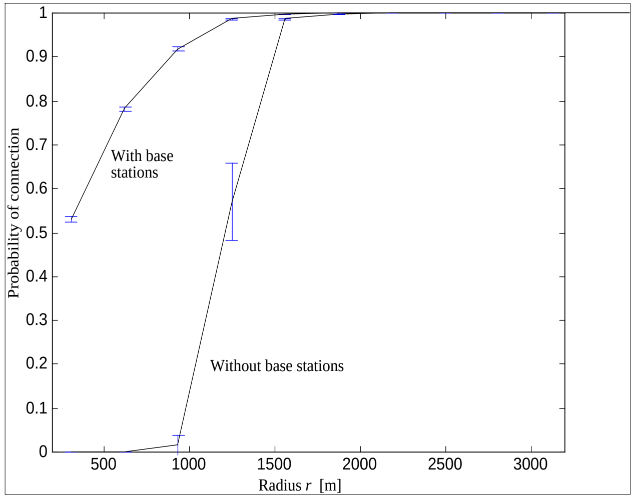
Source: Geographical Information Service (Geostat), Swiss Federal Statistical Office

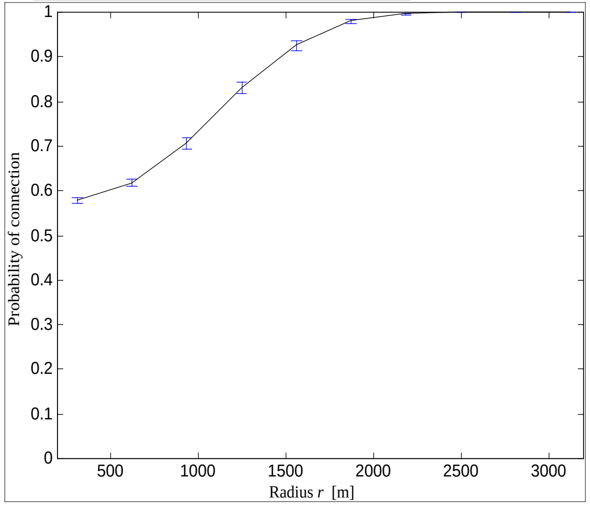


Zurich area



Surselva Alpine valley





Self-organized routing based on mobility diffusion

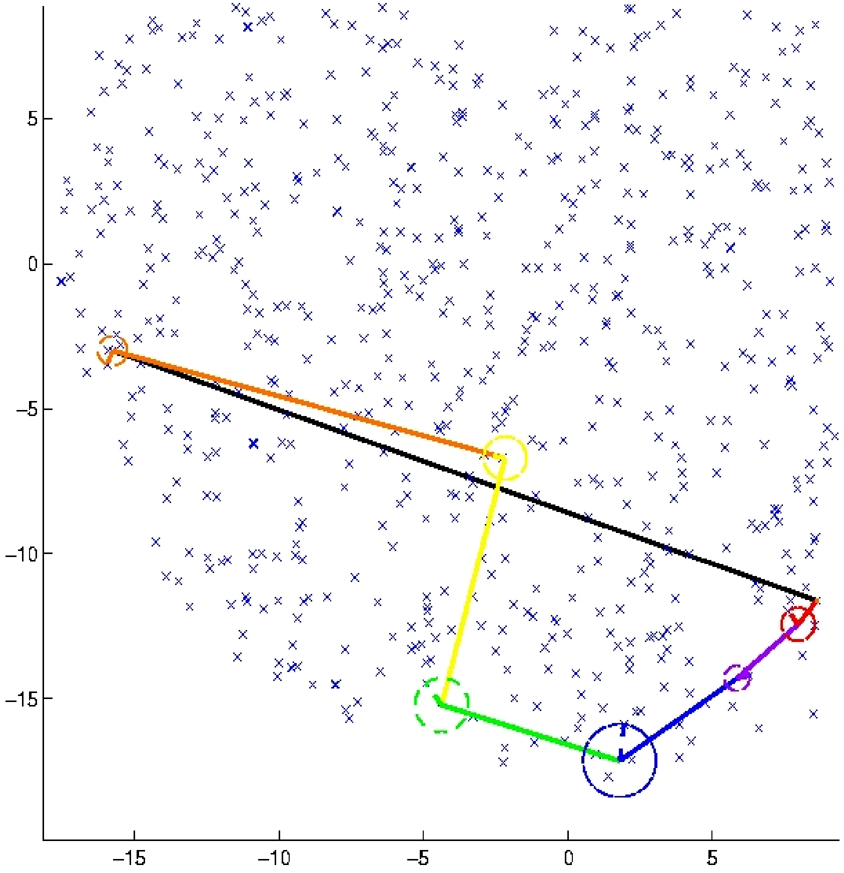
Example due to

M. Grossglauser, EPFL

Node mobility both challenge and opportunity:

- **Past work has exploited mobility through the channel fluctuation it generates -> diversity**

- **Exploit “information carrying capacity” of mobile nodes**



EASE: Exponential Age Search

Mobility

- Complicates matters
- Helps in other cases
- Problematic for software world -- changing environment/network properties

Aspect-oriented system design

- Key issue in design of a system:
  Separation of concerns [Dijkstra]
  - Concern --> aspect
- Why?
  - Evolution of system
  - Coherence of design
- How can it be realized?
  - Modularity
  - Components
  - Object-orientation
  - *Aspect-oriented programming*

Aspect-oriented programming

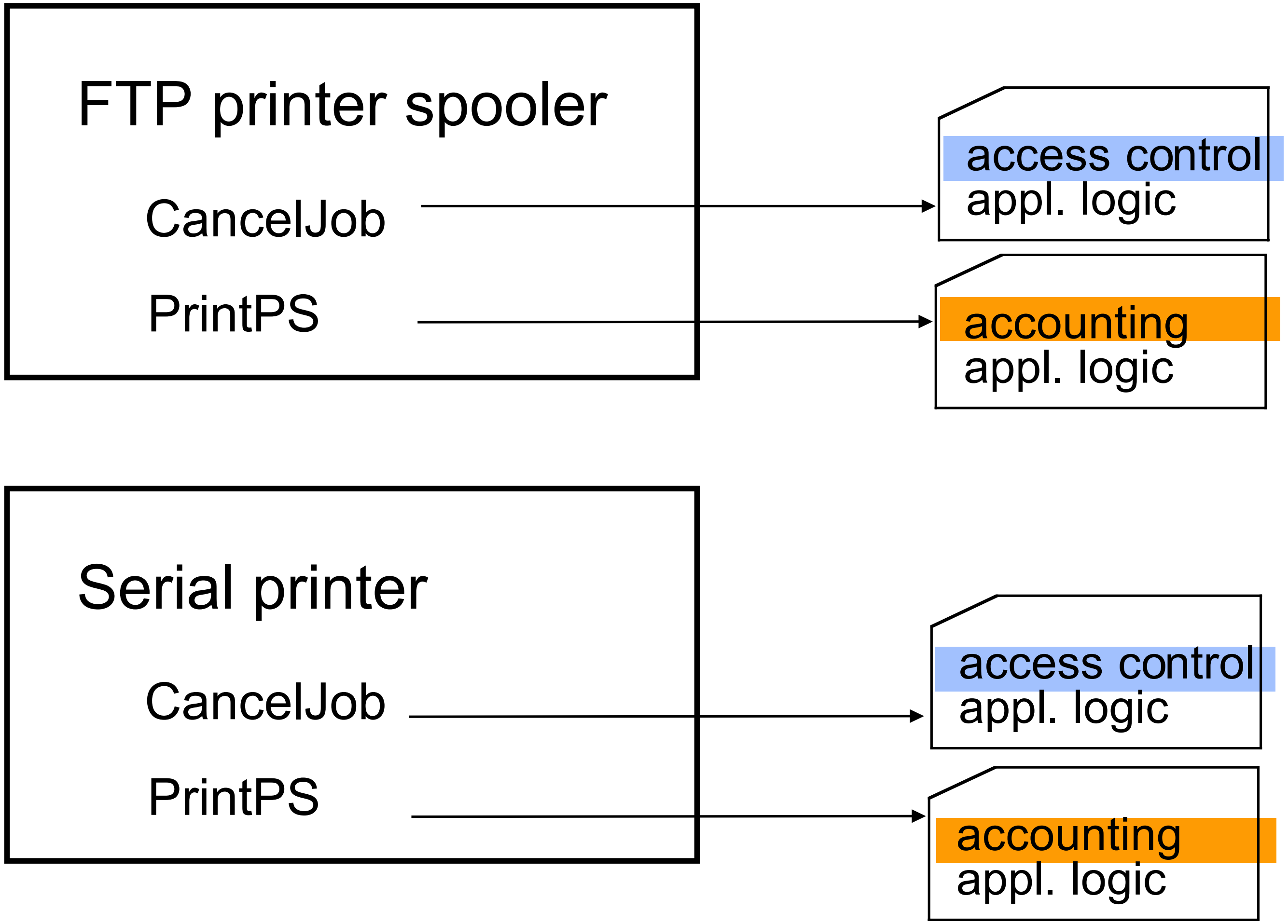
- “Untangle your code into cross-cutting, loosely coupled aspects" [Xerox AOP motto]
- Important early systems by Xerox PARC and IBM Research Lab
  - Aspect/J
  - Hyper/J
- Based on ideas developed by
  - Karl Lieberherr [NorthEastern]
  - Oscar Nierstrasz [Geneva, now Berne]

  - and many others ...

Aspect oriented programming

- System = application logic + advice(s)
- Advice
  - Code to deal with one issue (aspect)
- Combine advices with application logic
  - Join point: place where an advice can be invoked
  - This process is called *weaving*

Example


FTP printer spooler
CancelJob
PrintPS
access control
appl. logic
accounting
appl. logic
Serial printer
CancelJob
PrintPS
access control
appl. logic
accounting
appl. logic

Example

```
class ExampleAspect extends Aspect {
Crosscut doActl = new FunctionalCrosscut() {
public void ANYMETHOD(ANY anyThis, REST rst) {
  // access control code  }
  { setSpecializer(
    (MethodS.named(".*cancel.*")).AND
    (MethodS.BEFORE)); }
};
Crosscut doAccnt = new FunctionalCrosscut() {
public void print(ANY anyThis,byte[] b) {
  // accounting code }
  { setSpecializer(
    (MethodS.AFTER).AND
    (ClasseS.extending(Printer.class))); }
};
}
```

Aspect-oriented programming

- A number of systems have been designed
- Many variations
  - Use of “base” language
    - Application logic
  - Use of “advice” language
    - Special-purpose language
    - Base language
  - Specification of “join points”
  - Time of weaving
  - ...

Mobility requires adaptation

Ad hoc networks create a highly varying computing context:

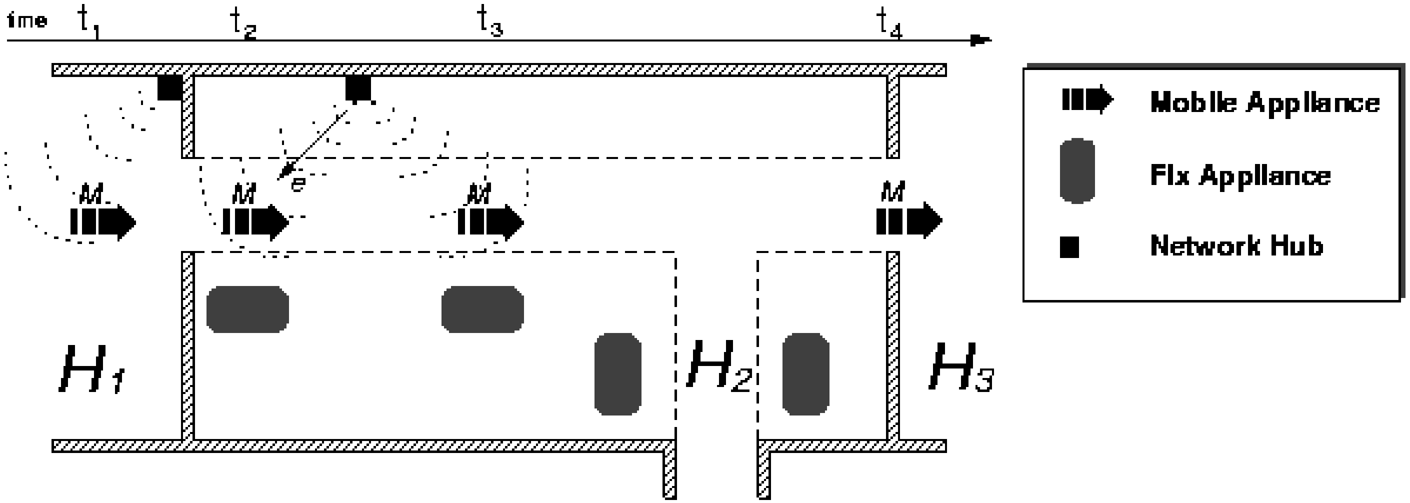
- neighbors appear and disappear, e.g., in peer 2 peer settings
- policies (e.g., security rules) change over time or depending on location

- Increased mobility → new locations → new contexts

Adaptation in mobile setting

- Setting: robots that work in an intelligent factory
- Robots move (goods) through the assembly halls H_1, H_2, H_3, ...
  - Local (resident) robots modify goods

Adaptation in mobile setting



- **Quality problems detected in production hall** *H_2*
- *M* **enters** *H_2* **→ it receives a run-time extension** *e* **from** *H_2*
- ***e*** **adds *at run-time,* on-the fly, functionality for**
  - **Monitoring all motor moves, sensor reads, incoming and outgoing messages**
  - **Records this information in an** *H_2***–specific database**

Aspect-oriented programming

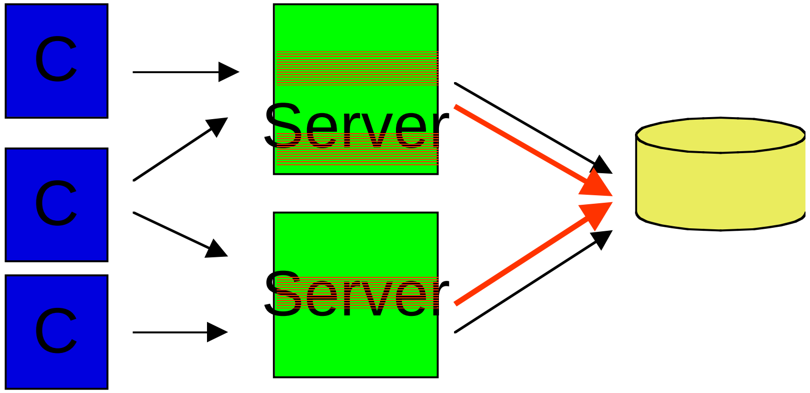
- AOP provides an approach to modify software
  - Apply this idea to implement adaptation
- “Dynamic AOP”
  - AOP “on the fly”
- Many issues
  - Security
  - Performance
  - Programming model

PROSE - dynamic AOP

- PROSE - PROgrammable extenSions for sErvices
- Aspect-oriented programming for mobile systems
  - Base language: Java
- Joint work with A. Popovici and G. Alonso
  - Special thanks to A. Popovici for allowing me to use material from his (upcoming) thesis

Managed networks

- Long-running service application
- Costly to shut down or re-deploy
- Issue: How to apply fixes, monitoring
  - site-specific policies *at unexpected locations* in the code?

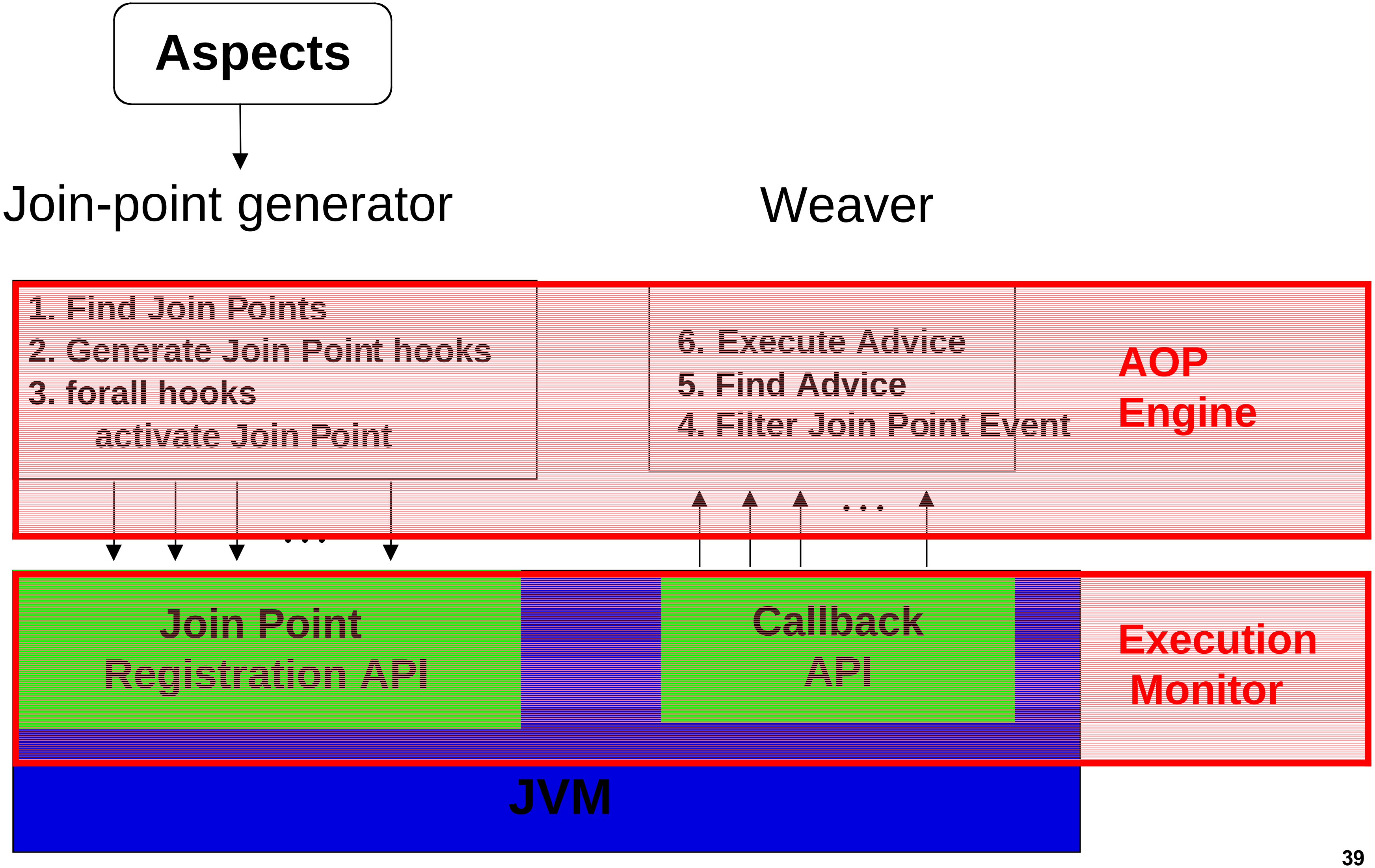


Problem and solution space

- **Adapt:**
  - multiple computing nodes
  - at multiple points in their execution
  - at various points in time (hot fixes) and space (mobility)
- **Responsibility of adaptation: in the computing context**

- **Divide problem in sub-problems**
  - infrastructure for adapting individual nodes
  - infrastructure for adapting entire node communities

AOP System architecture



Aspects

Join-point generator

Weaver

1. Find Join Points
2. Generate Join Point hooks
3. forall hooks
   activate Join Point

6. Execute Advice
5. Find Advice
4. Filter Join Point Event

Event-based model

- Simple and general model
- Can be used by multiple AOP engines

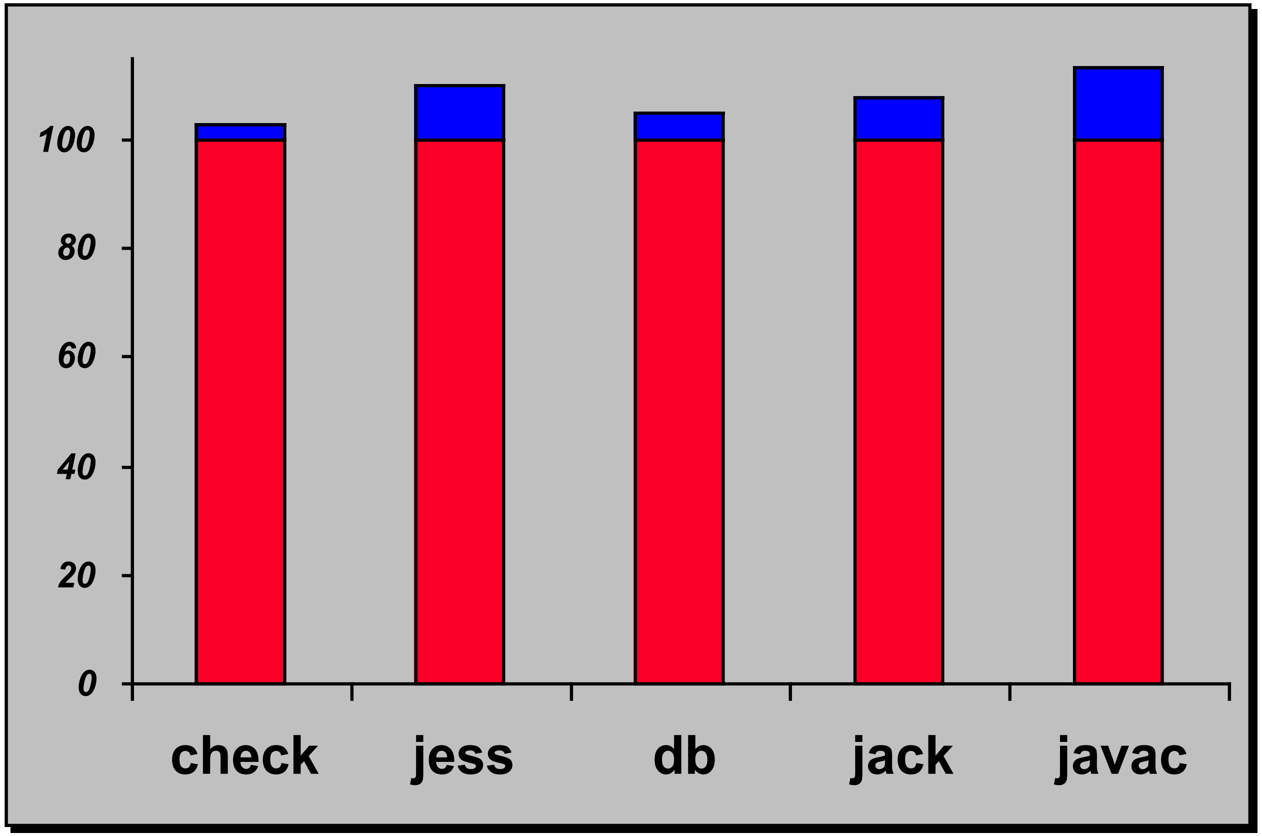
- Issue: implementation cost

Execution monitor

- Implementation
  - Jikes RVM, v. 2.0.2
  - Baseline JIT compiler
  - 1600 lines of code added to the VM core
  - Changes affect several JVM modules (Garbage Collector)

Performance -- normal execution (R2)

- Performance penalty: < 10%
- Benchmark: SpecJVM 98

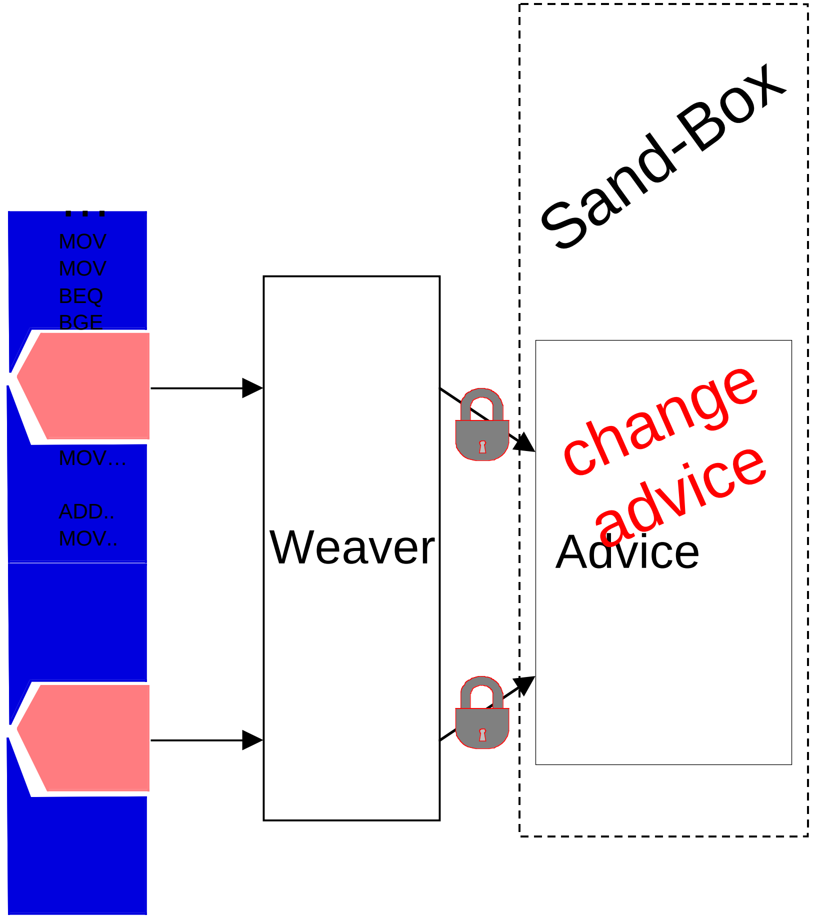


Security

Weaving can be secure

AOP operations can be easily made transactional

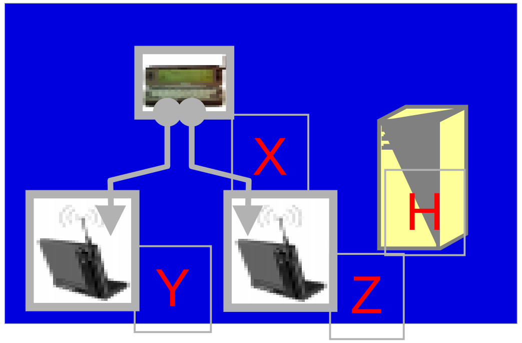
Other AOP Engines can be built on top of the same Execution Monitor

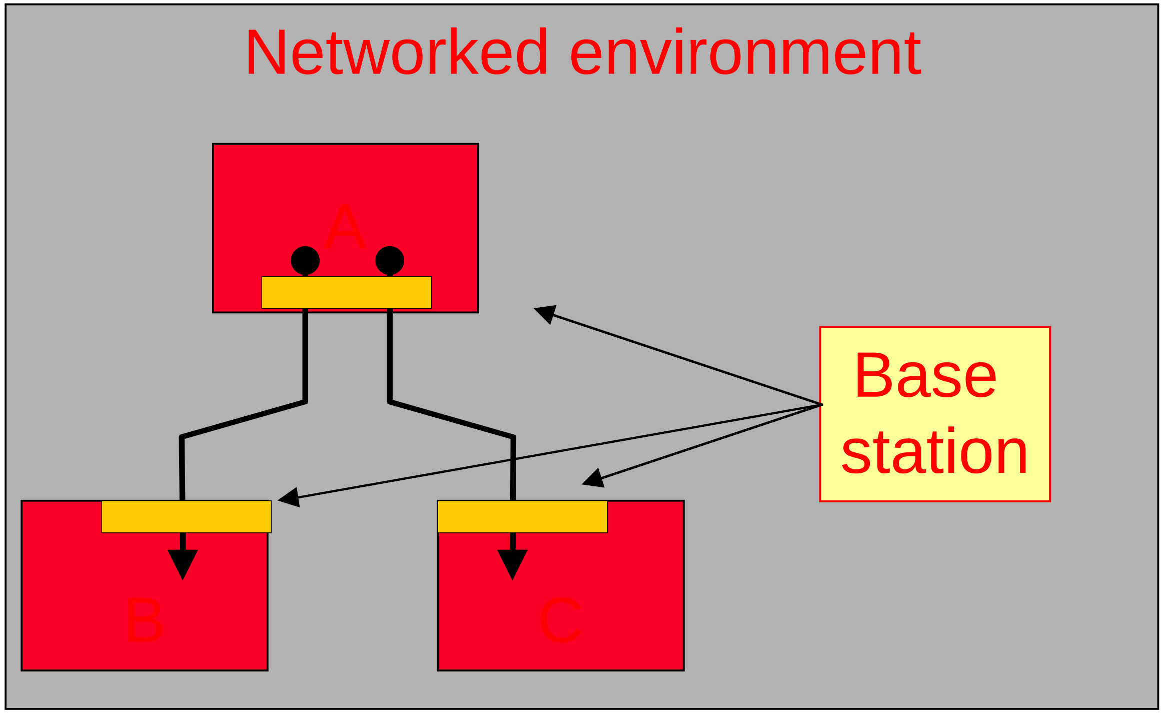


Ad hoc endpoints

- Individual nodes
  - AOP with PROSE
- “Information systems” applications
  - … next …

“Spontaneous containers”

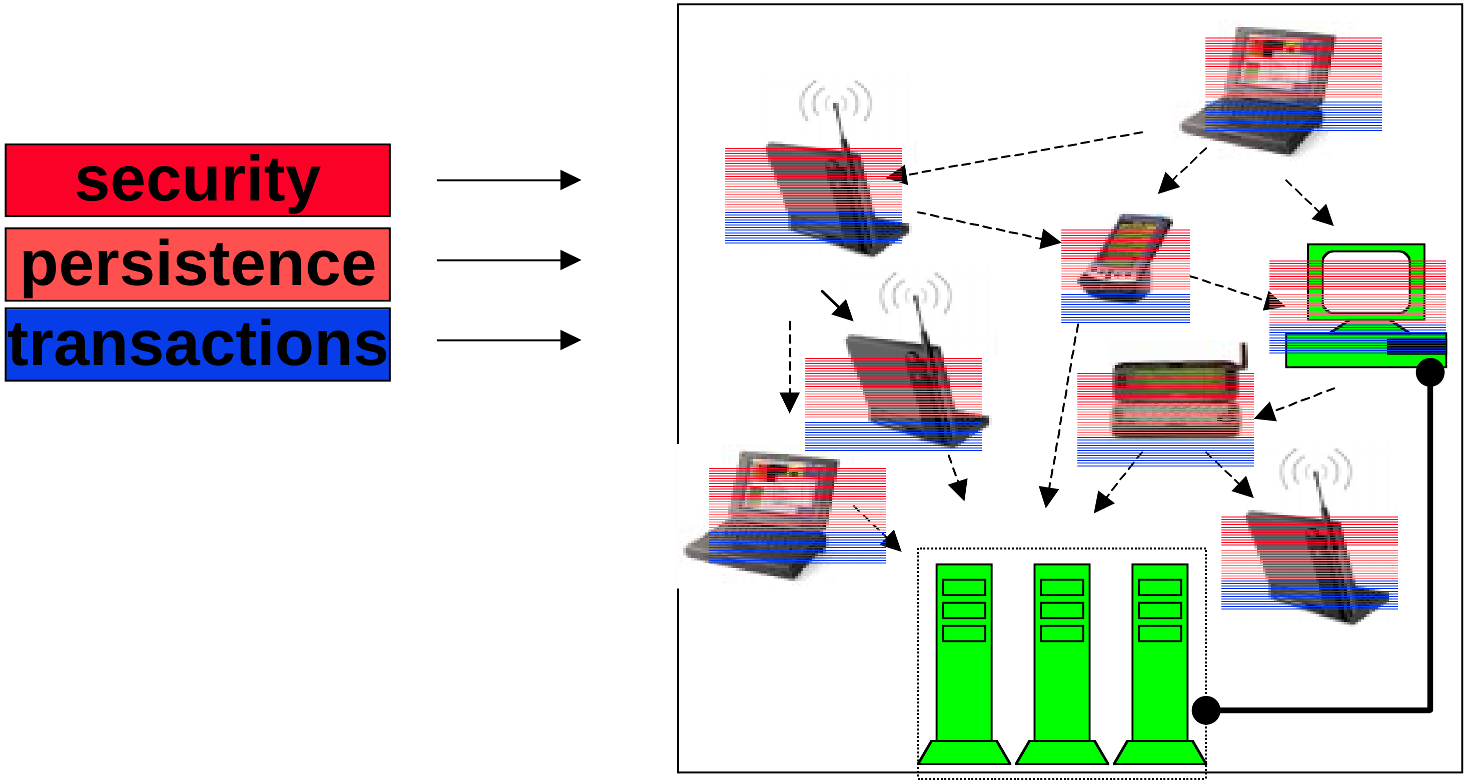




- The networked environment acts like a container
- The applications interact dynamically
- Extensions use dynamic AOP to express adaptations

Spontaneous containers

- Allow new kinds of applications
- Ad hoc and spontaneous networking



security

persistence

transactions

WiFi, 4G, and the telcos’ debt

- Software solutions offer portablilty
  - Only a few [large] systems are used exclusively for the design tasks
    - Profits and key benefits sometimes elsewhere
    - Internet: NSW (National Software Works) -- email
  - Some systems good for nothing
- High-bandwidth WLANs attractive
  - People willing to pay
- G4 spectrum looking for a use, telcos looking for a way to recoup outlays
  - Mobile users create “ad hoc” networks

Challenges

- How to design, implement, test, and evolve adaptive systems
- Nobody (very few ...) an expert on all sub-areas of ad hoc networks
  - Layers a necessity and a problem
  - How to get (academic) researchers to self-organize
- How do we educate the next generation of researchers
  - If possible, can we maybe also create a few jobs? (or at least preserve a few ones?)

Thanks

- G. Alonso
- J. Bovay
- O. Dousse
- M. Grossglauser
- A. Popovici
- P. Thiran
- M. Vetterli

Swiss National Science Foundation
EPFL
ETH Zürich
Geographical Information Service (Geostat)
Swiss Federal Statistical Office

all participants in NCCR MICS

Concluding remarks

- Software crucial if we want to support *applications* on ad hoc networks
  - ... is that different from other networks?
- New constraints and requirements
    - Software systems are difficult to design and implement
  - Must deal with need to adapt
  - Aspect-oriented system design an interesting model
    - Resource demands and prediction still an issue
- Many good, hard questions remain.

Thank you for your attention.