Engineering Self-organising Coordination
A Computational Field Approach

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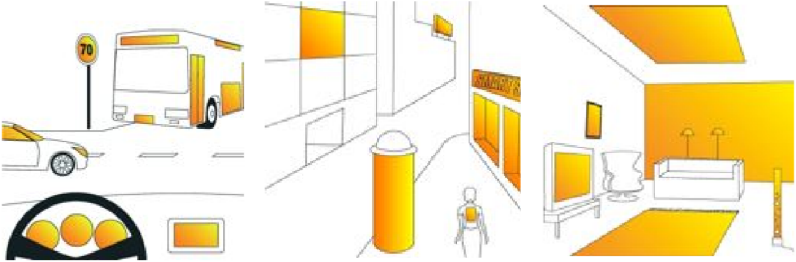
Outline

Tomorrow living and computational environments



(Pict. by A. Ferscha, JKU)

Impact on the computational model

Towards new levels of complexity on:

- Scale: devices are very dense (forming a continuum)
- Situatedness: data/events are tightly linked with space
- Distribution: most situations and events are distributed
- Opennes: highly unpredictable working conditions
- Mobility: continuous relocation, new deployments in the short-term

Requirements for coordination models

- Adaptation: services should face unexpected distributed contingencies
- Emergence: no full design-time awareness of system behaviour

⇒ Self-organisation: creation of "function" with no global supervision

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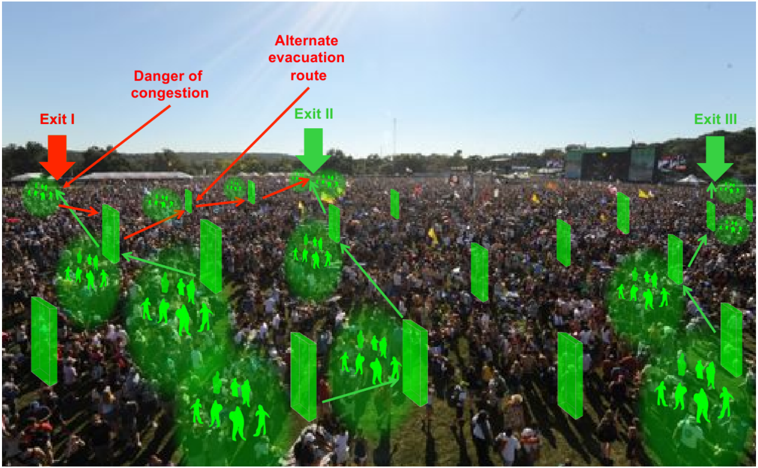
Crowd Engineering – www.sapere-project.eu



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An increasingly interesting business for coordination

Advanced coordination mechanisms

- Coordinating sensing/acting in complex situations
- Opportunistic exploitation of contextual information
- Dealing with user (implicit) preferences, intentions, social network
- Anticipation of future contingencies
- Spontaneous aggregation/composition of data/functions

Some application scenarios

- Pervasive computing (crowd steering, coordinated visualisation)
- Sensor networks (aggregating/diffusing data, complex recognition)
- Swarm and modular robotics (cooperative team work)

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1. Emerging Pervasive Computing Scenarios and Coordination
2. Self-organising Coordination by Computational Fields
3. Some recent result
4. Conclusions

Self-organisation meeting space-based coordination

Going to the aggregate: from tuples to fields of tuples

- Tuples are pointwise abstractions, reifying single events/data
- Shall move to "distributed groups" of tuples as first-class abstraction
  - Best known as computational fields, or co-fields
  - Created by nondeterministic aggregation/diffusion processes
  - Acting as "global self-adapting and self-organising" structures

Previous works and attempts

- TOTA middleware for co-fields [Mamei and Zambonelli, 2009]
- Biochemical TSs, $\sigma\tau$-Linda [Viroli et al., 2012, Viroli and Casadei, 2009, Viroli et al., 2011]
- SAPERE framework [Zambonelli et al., 2011]

⇒ still lacking a solid stack of models, langs, patterns, platforms, apps

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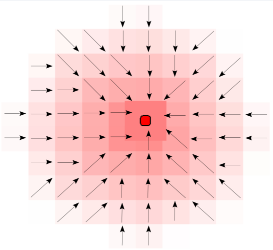
The gradient case

The gradient field as a key building block

Spreading: $x \Rightarrow x \,|\, (x+1)^{\rightsquigarrow}$ *Aggregation:* $x \,|\, y \Rightarrow min(x, y)$

- In each node minimal distance to the source (where $x = 0$) stabilises
- Usages: advertising, routing, relocation, distributed aggregation

Gradient shape (discrete, flat continuous, structured continuous)



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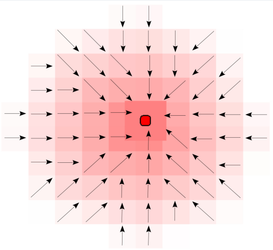

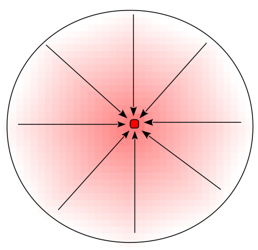

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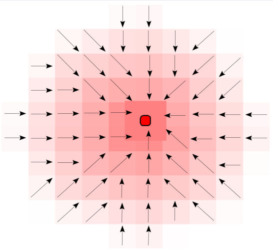
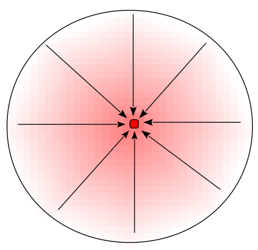
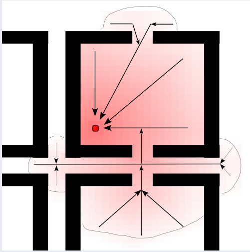




Layers in engineering computational fields

Low level – single-device capabilities: aggregation, diffusion, decay,..

- Theory: component/interaction models
- Practice: supporting platforms

Mid level – constructs to express/compose fields

- Theory: formal languages and properties
  (self-stabilisation, expressiveness, convergence with increasing density)
- Practice: coordination languages, libraries of patterns

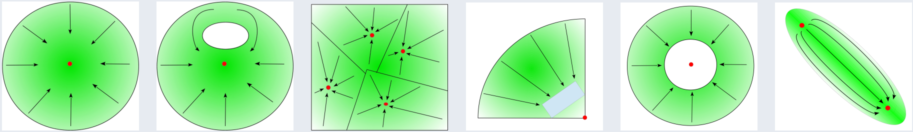
Top level – perception/actuation over fields: chemotaxis, morphogenesis

- Theory: usage patterns, comprehensive languages, agent models
- Practice: information routing, crowd steering, distributed recognition

Outline

Early results (1/3): Towards a catalogue of patterns

A set of patterns [Montagna et al., 2013]



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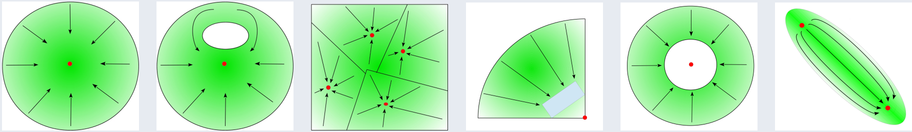
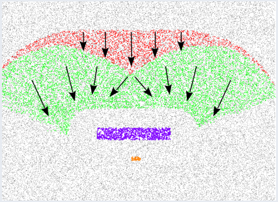
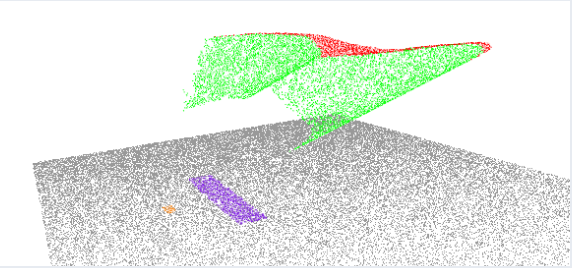


Anticipative gradient [Montagna et al., 2012]





Early results (2/3): Models/languages to express fields

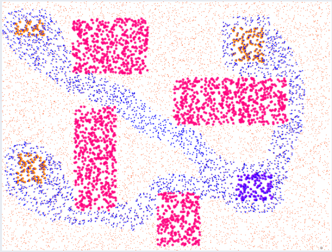
Several proposals in the past

- See a survey in [Beal et al., 2013] – few of them in coordination
- Trying to balance expressiveness and tractability [Viroli, 2013]

A recent core calculus: "[{..} ..]"

```
def If(FIELD,WHERE) is
     WHERE ? FIELD : #undef
def Gossip(VAL) is
     [{VAL}]
def Grad(SRC,OBS) is
     [If({SRC}+1,not(OBS))]
def Dist(SRC,DST,OBS) is
     Gossip(If(Grad(SRC,OBS),DST))
def Chan(S,D,O,W) is
     Grad(S,O) + Grad(D,O) + W < Dist(S,D,O)
```

..and the resulting "channel"



Early results (3/3): Confluence and Self-Stabilisation

The problem of formal properties

- Predict/control the final outcome of a field computation
- Find sufficient conditions for certain key properties – self-stabilisation

Generating confluent fields [Viroli, 2013]

Considering the fields expressed in the language above

- Theorem: they all are confluent and self-stabilising

⇒ Sufficient conditions

1. There is a noetherian order relation over data
2. The functions connecting "[]" and "{}" are monotonic and progressive
3. No recursive calls

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The direction of "self-organising coordination"

- Self-org and coordination will inevitably and increasingly combine
- Engineering self-organisation is challenging..
- ..coordination people can contribute a lot
- Coordination fields as a candidate first-class abstraction

Perspectives

- Self-org coordination can target many objectives of Horizon 2020
- It can be a good ingredient of proposals under different umbrellas
  - ⇒ adaptation, autonomic computing, collective systems, future ICT, SmartCities, Internet of things, Socio-technical systems

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SAPERE

Self-Aware Pervasive Service Ecosystems, under contract no. 256873.

CINA Italian PRIN Project

In the next 3 years CINA Project in Italy will provide a container for nurturing some tasks of this research thread (Rocco de Nicola as leader)

CINA

Compositionality, Interaction, Negotiation, Autonomicity for the future ICT society

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