Hypernetworks and Design for Non-Equilibrium Global Systems Science

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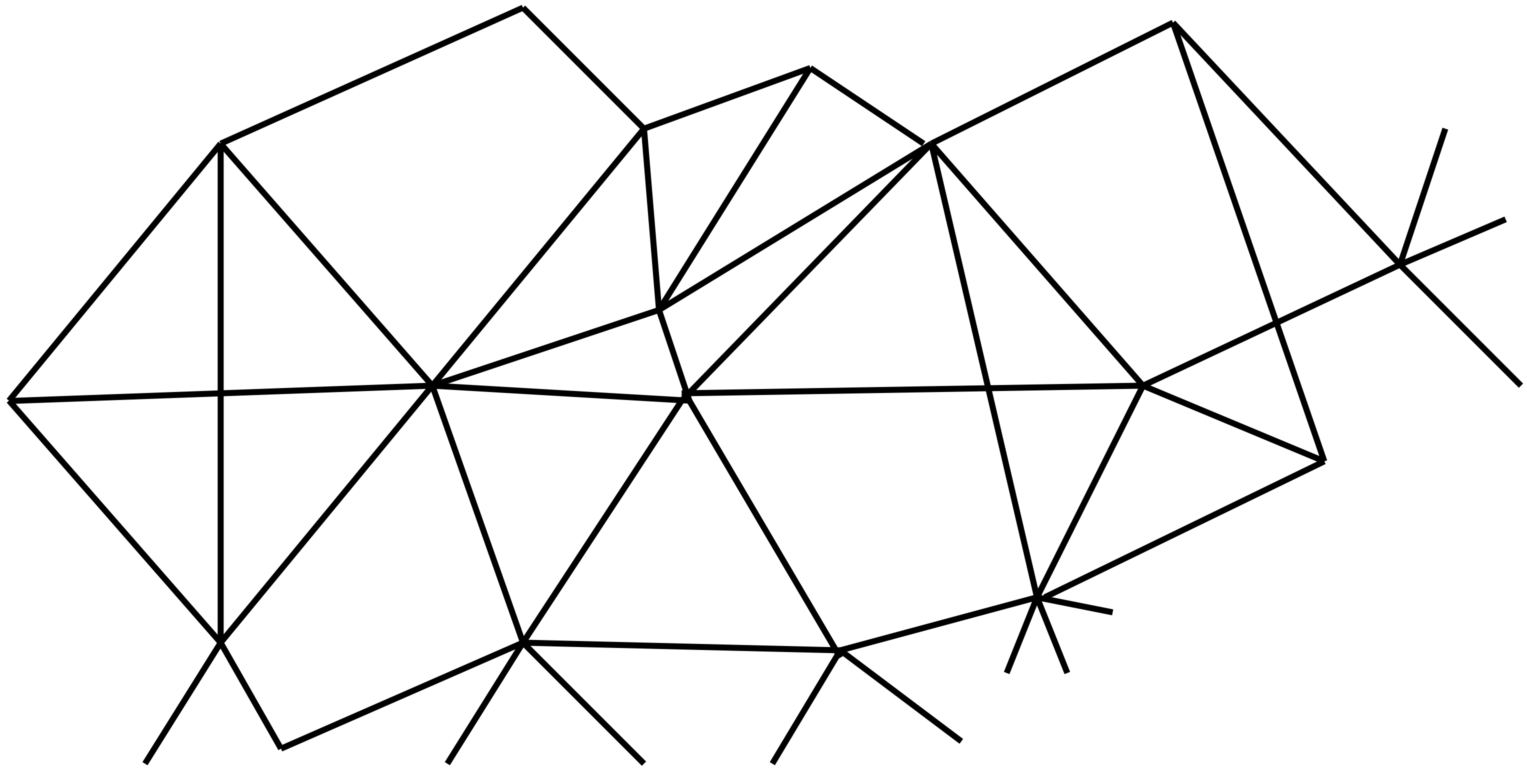
Hypernetworks

Networks can represent relationships between pairs, < x, y >

e.g. x trades with y



Hypernetworks

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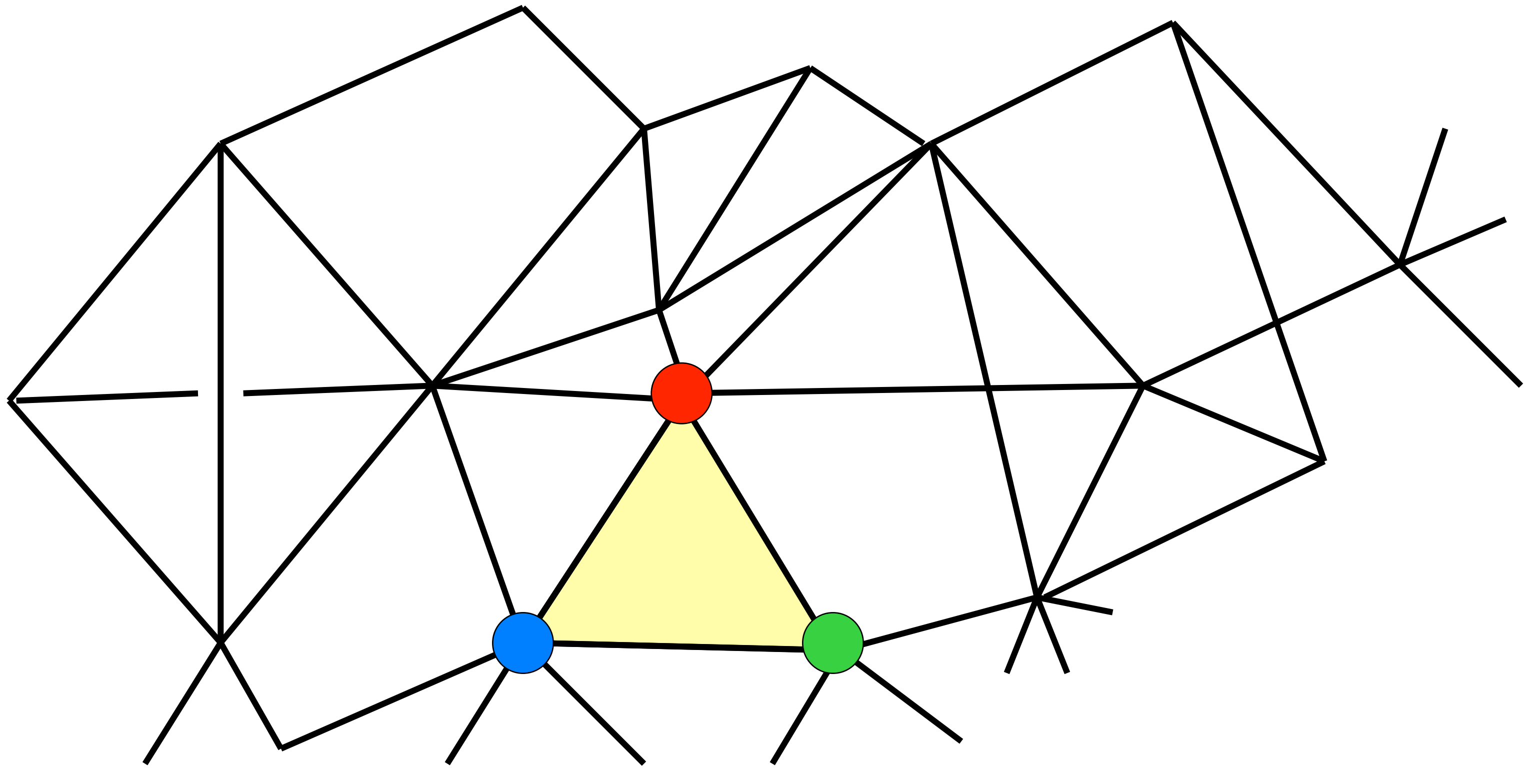

What about relationships between three thing, < x, y, z >

e.g. x , y and z form an oligopoly.

Hypernetworks

Networks can represent relationships between pairs, < x, y >

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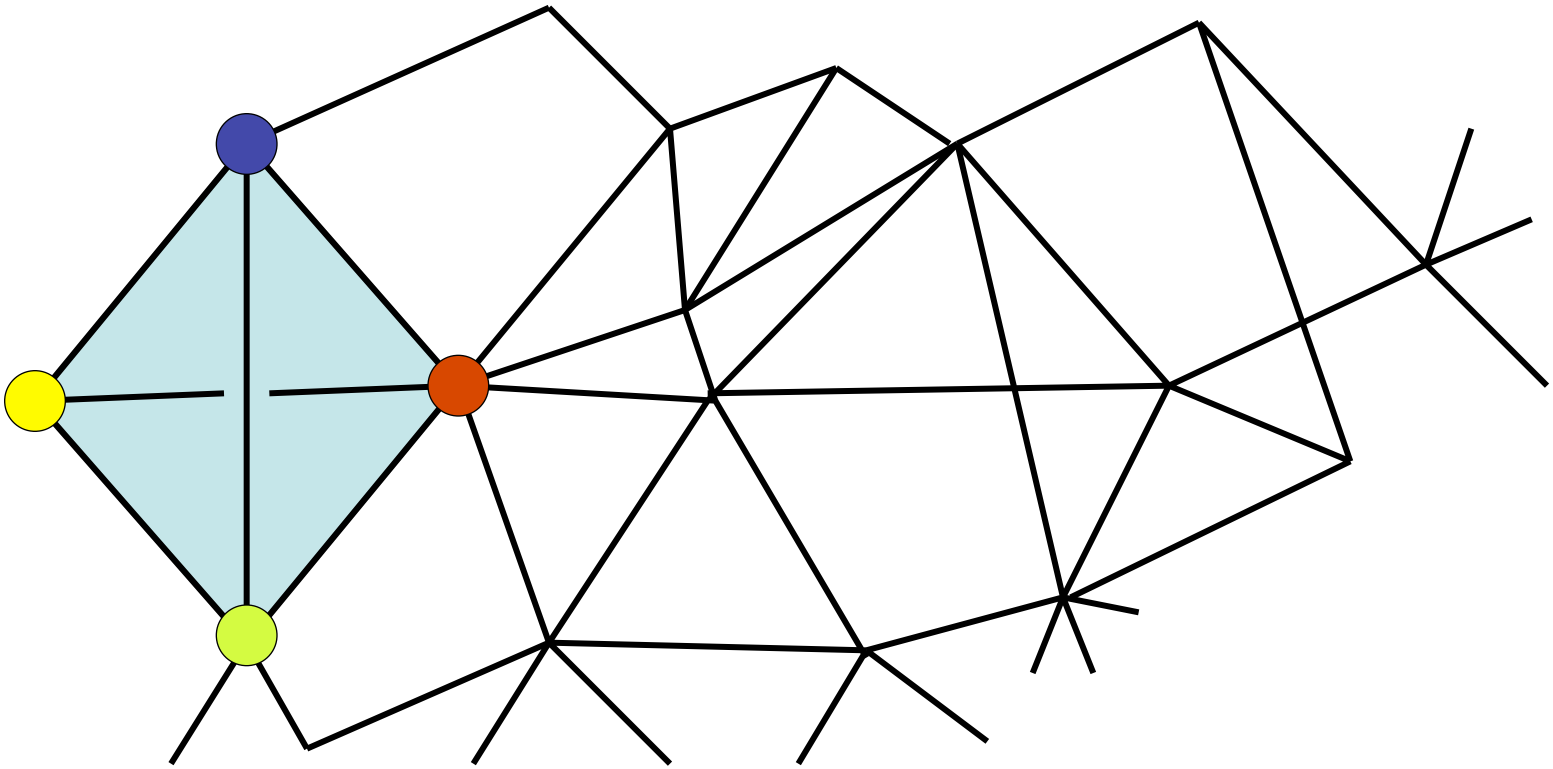


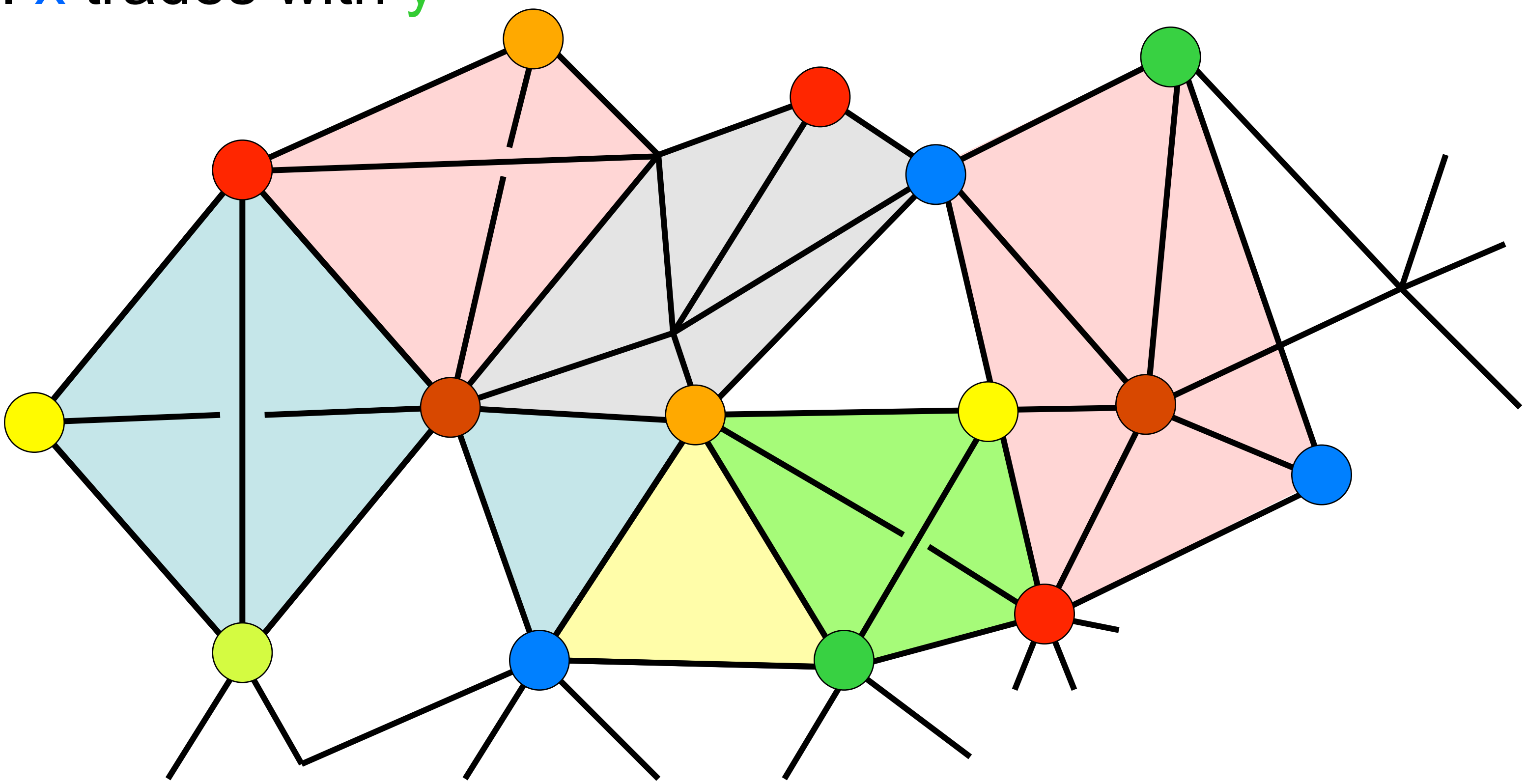
What about relationships between three thing, < x, y, z >

e.g. x , y and z form an oligopoly. Or a relation between 4 things

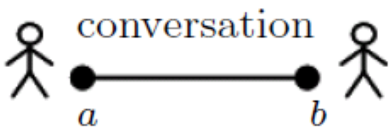
Hypernetworks

Networks can represent relationships between pairs, < x, y >

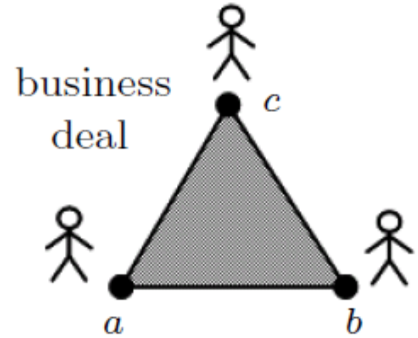
e.g. x trades with y



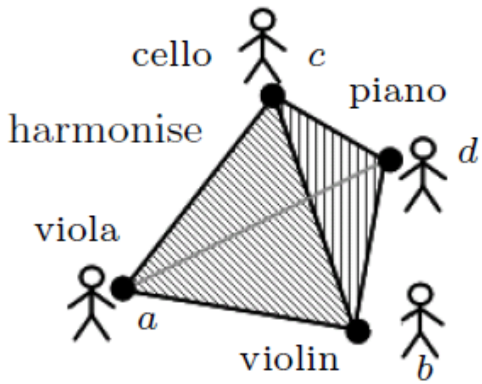
Or any number of things …



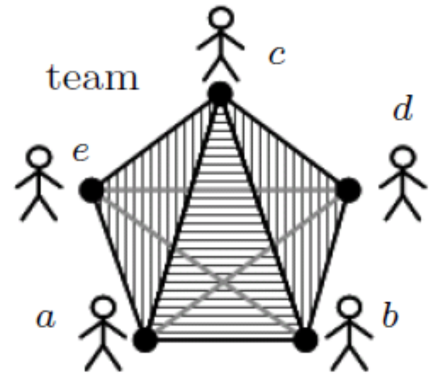
(a) line 1-dimensional



(b) triangle 2-dimensional



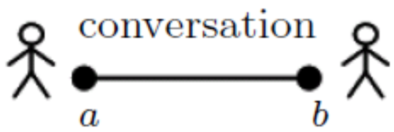
(c) tetrahedron 3-dimensional



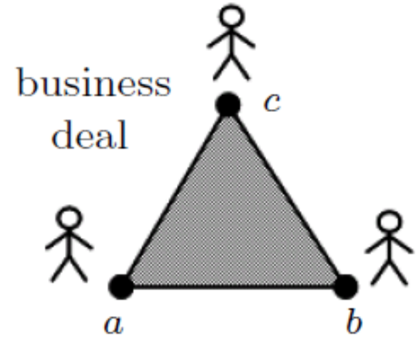
(d) pentahedron 4-dimensional

The generalisation of an edge in a network is a *simplex*

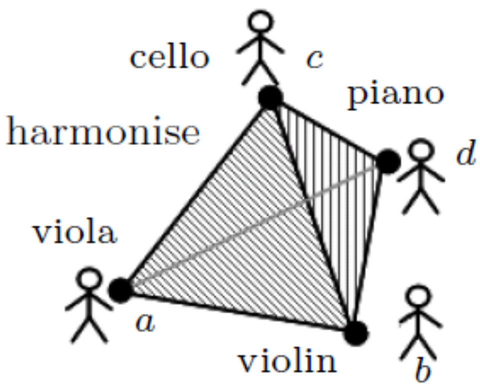
Simplices can represent *n*-ary relation between *n* vertices



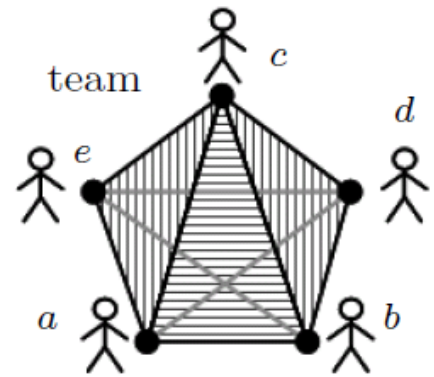
A 1-simplex ⟨a, b⟩ has 2 vertices



A 2-simplex ⟨a, b, c⟩ has 3 vertices



A 3-simplex ⟨a, b, c, d⟩ has 4 vertices



A *p*-simplex $\langle v_0, v_1, \ldots v_p \rangle$ has *p+1* vertices

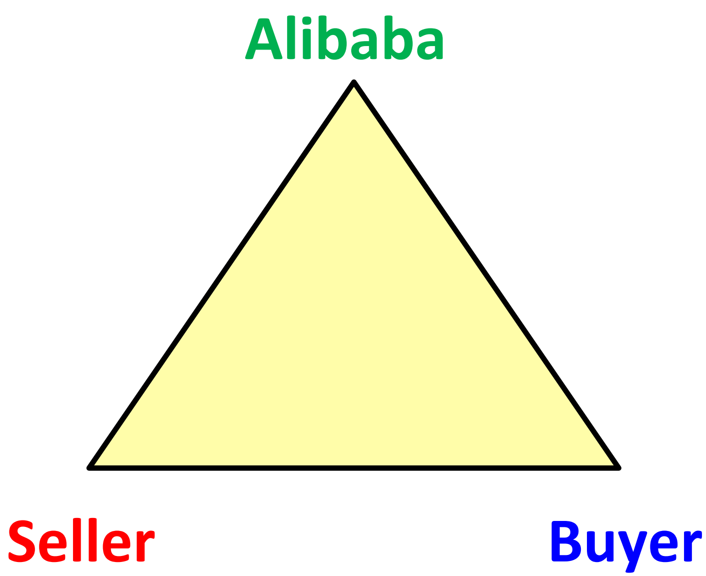
The generalisation of an edge in a network is a *simplex*

A *p-dimensional simplex* has *p+1* vertices

From Networks to Hypernetworks

Binary relations & links are essential

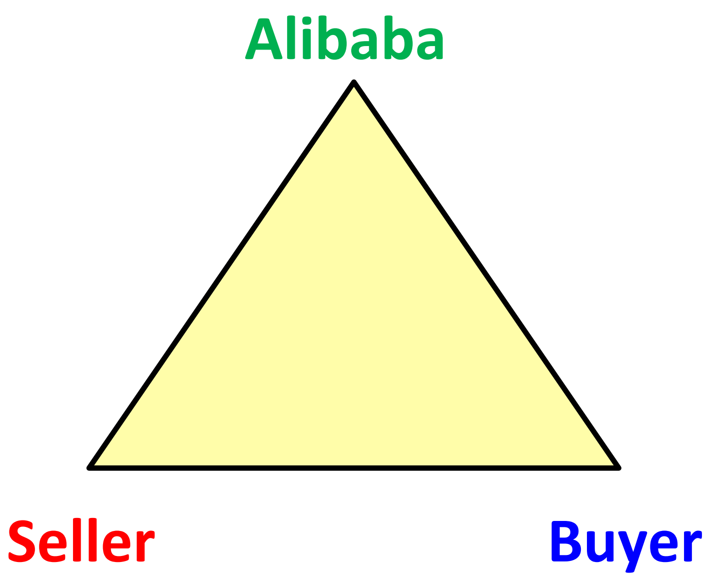
But we also need n-ary relations, n > 2



From Networks to Hypernetworks

Binary relations & links are essential

But we also need n-ary relations, n > 2

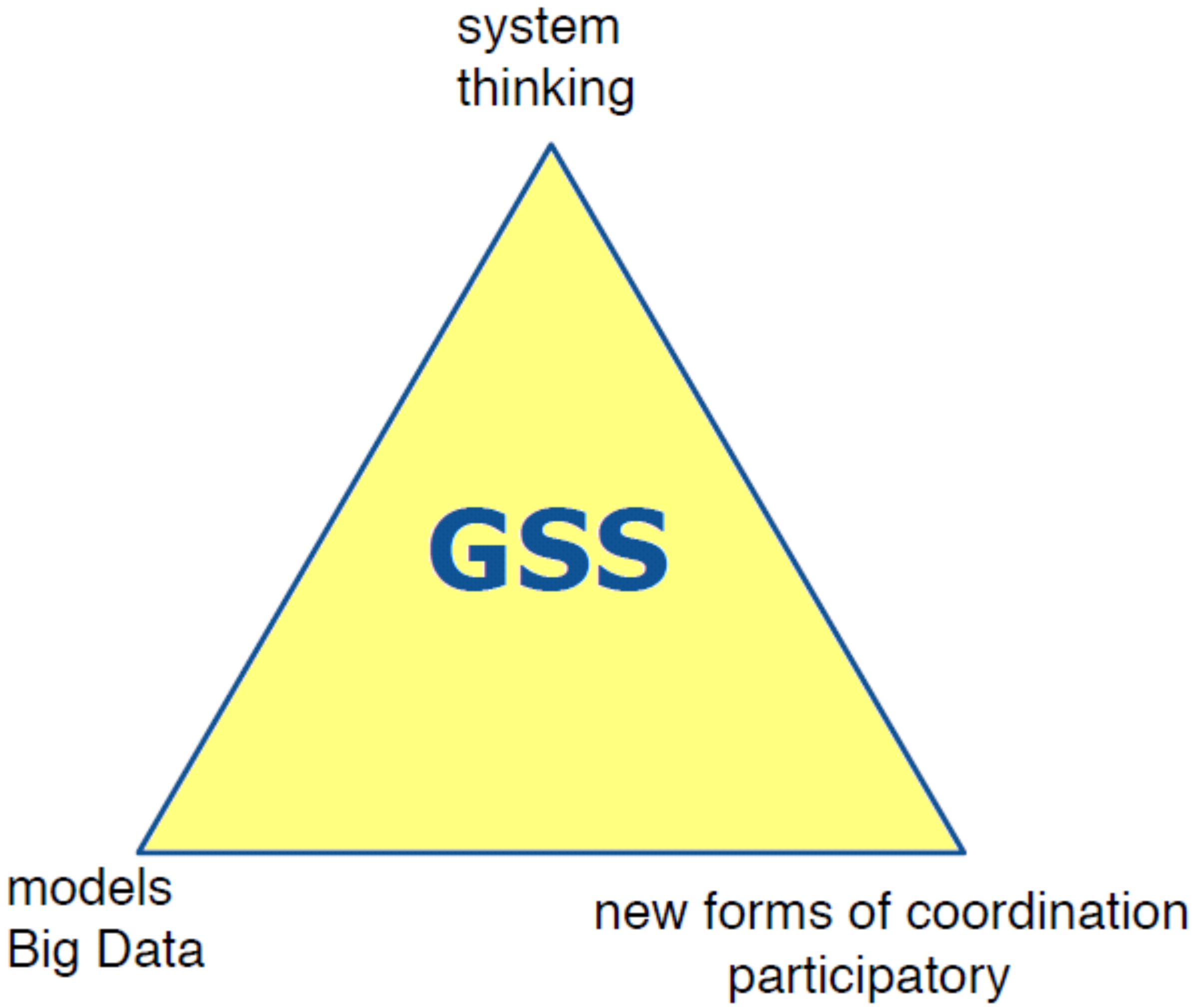


This is a 3-ary relation

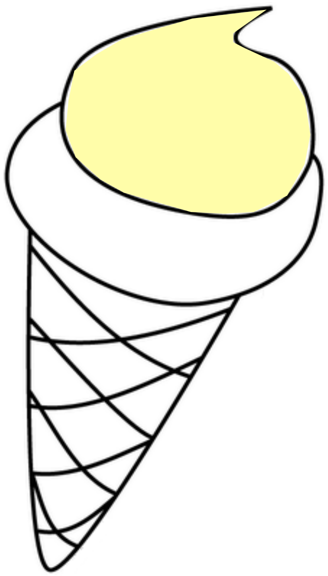
Remove any vertex and there cannot be this transaction

The transaction is a `whole'

Global Systems Science as a 2-simplex (source: Ralph Dum)



From Networks to Hypernetworks



Gestalt Psychologist Katz:

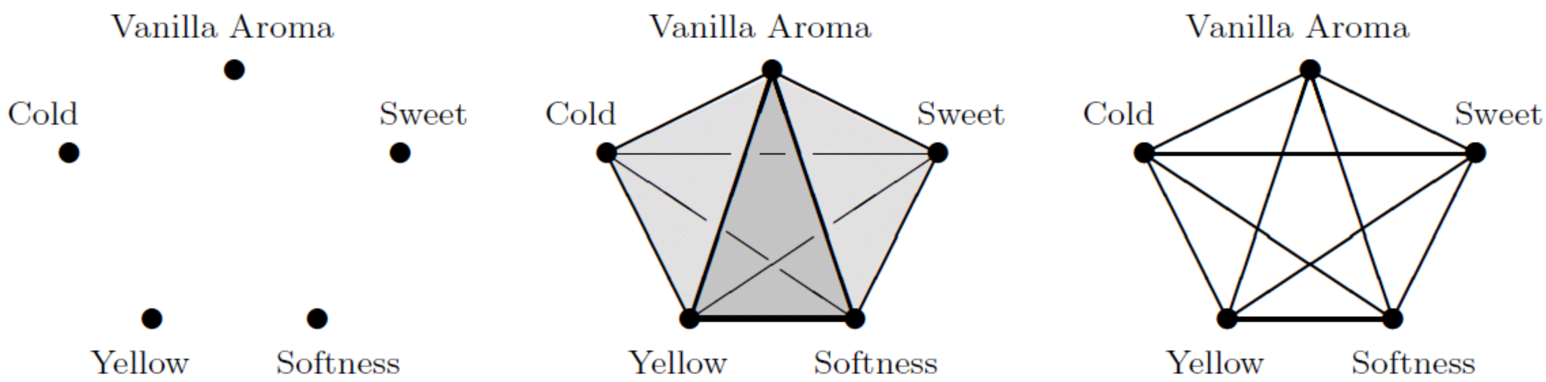
Vanilla Ice Cream ≠ cold + yellow + soft + sweet + vanilla

it is a Gestalt – experienced as a whole

⟨ cold, yellow, soft, sweet, vanilla ⟩

From Networks to Hypernetworks

$$\langle \text{Cold, Sweet, Vanilla, Soft, Yellow} \rangle \neq \langle \text{Cold} \rangle + \langle \text{Sweet} \rangle + \langle \text{Vanilla} \rangle + \langle \text{Soft} \rangle + \langle \text{Yellow} \rangle$$



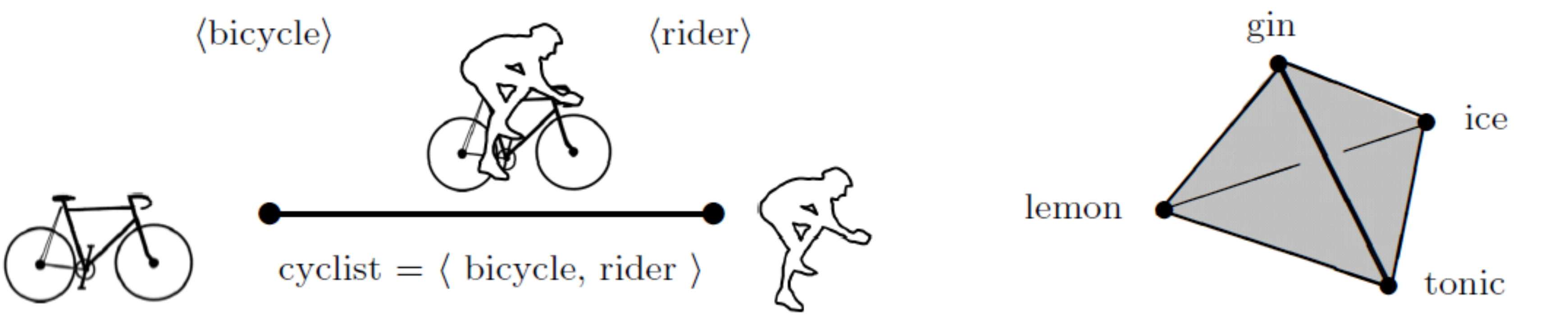
(a) a set of vertices (b) a polyhedron (c) a clique

set of vertices ≠ simplex ≠ clique

⟨ cold, yellow, soft, sweet, vanilla ⟩

Simplices represent wholes

… remove a vertex and the whole ceases to exist.



(a) Remove a vertex and the cyclist simplex ceases to exist

(b) Remove a vertex and the perfect gin and tonic ceases to exist

Fig. 4.8 Remove a vertex and the simplex ceases to exist.

Time t

The girls all like each other pairwise

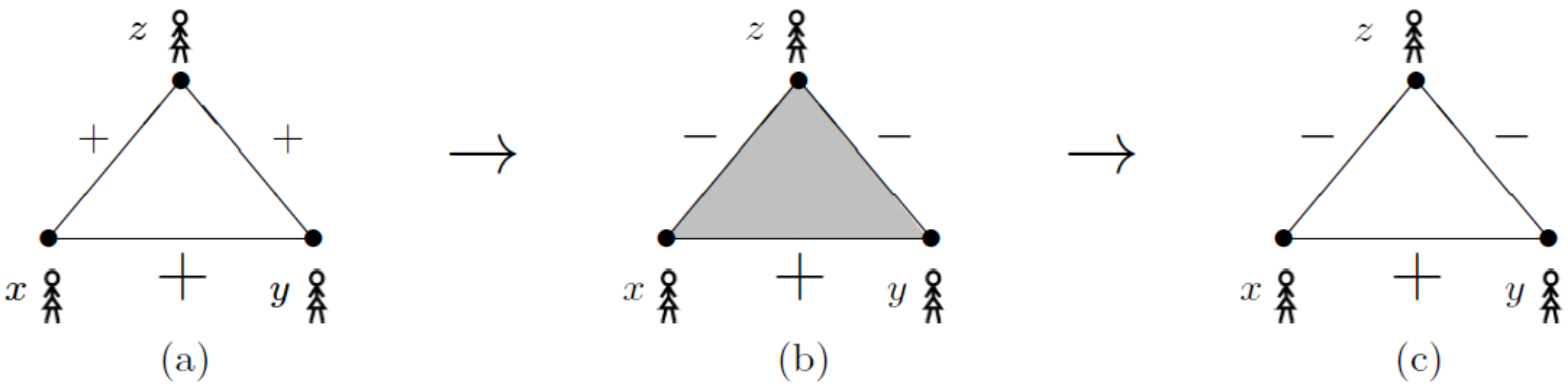


Fig. 4.4 Social dynamics depend on structure

Time t

The girls all like each other pairwise

Time t+1

Two girls gang up on one when they play together as a

2-simplex

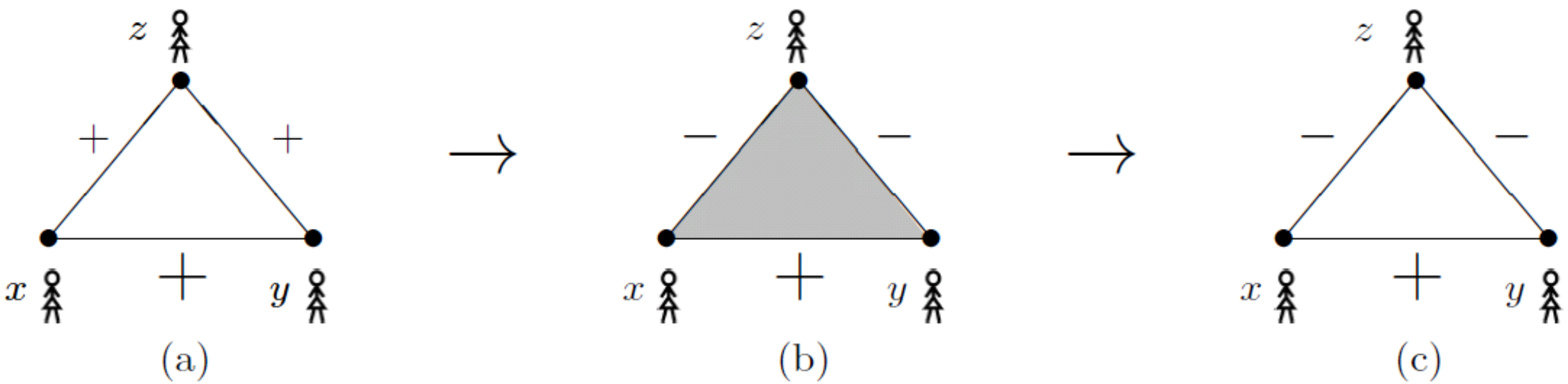


Fig. 4.4 Social dynamics depend on structure

Time t

The girls all like each other pairwise

Time t+1

Two girls gang up on one when they play together as a 2-simplex

Time t+2

The 3-way interaction has changed the pairwise relations

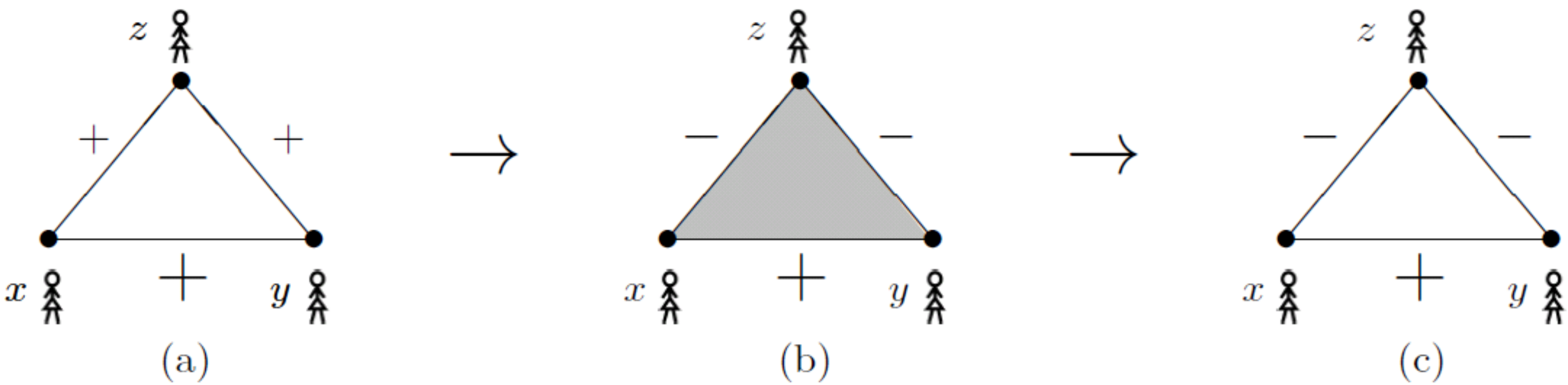
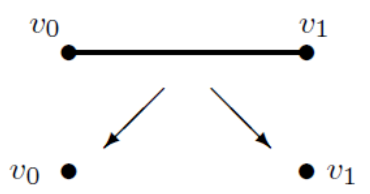
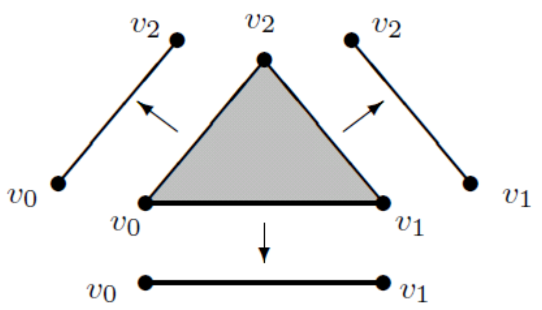


Fig. 4.4 Social dynamics depend on structure

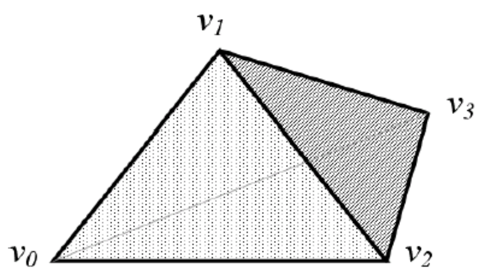
Simplices have multidimensional faces



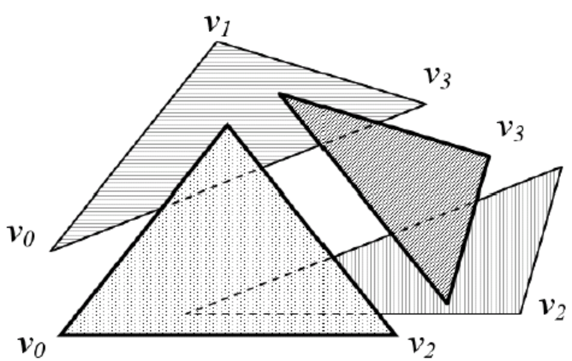
(a) vertices are 0-dimensional faces
of 1-dimensional edges



(a) edges are 1-dimensional faces
of 2-dimensional triangles



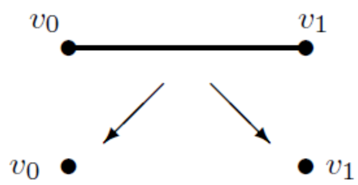
(a) a solid 3-dimensional tetrahedron



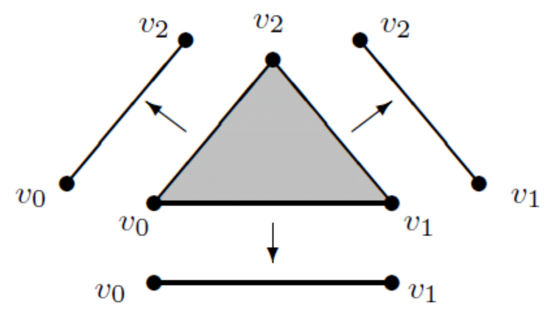
(b) the 2-dimensional faces of the tetrahedron

Fig. 4.9 The 2-dimensional triangular faces of a 3-dimensional tetrahedron

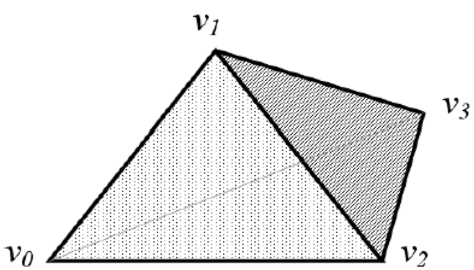
Simplices have multidimensional faces



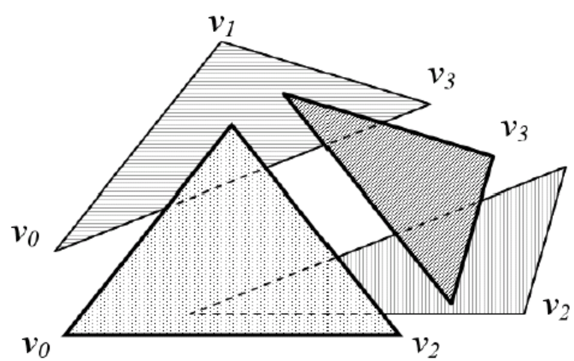
(a) vertices are 0-dimensional faces of 1-dimensional edges



(a) edges are 1-dimensional faces of 2-dimensional triangles



(a) a solid 3-dimensional tetrahedron



(b) the 2-dimensional faces of the tetrahedron

Fig. 4.9 The 2-dimensional triangular faces of a 3-dimensional tetrahedron

A set of simplices with all its faces is called a *simplicial complex*

Simplices have multidimensional connectivity through their faces

Share a vertex

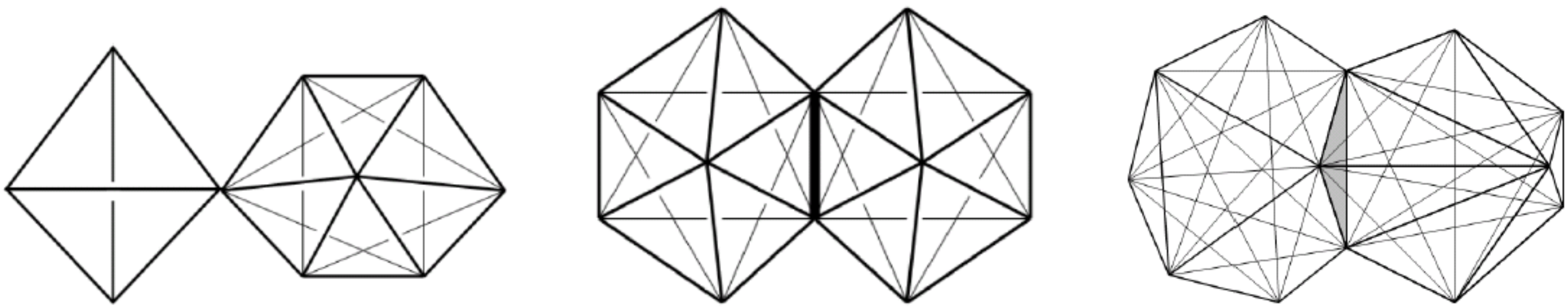
0 - near

Share an edge

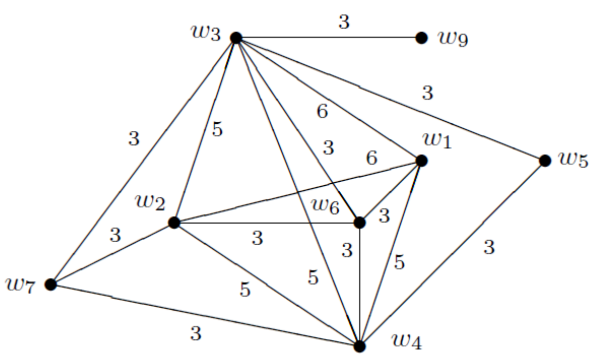
1 - near

Share a triangle

2 - near

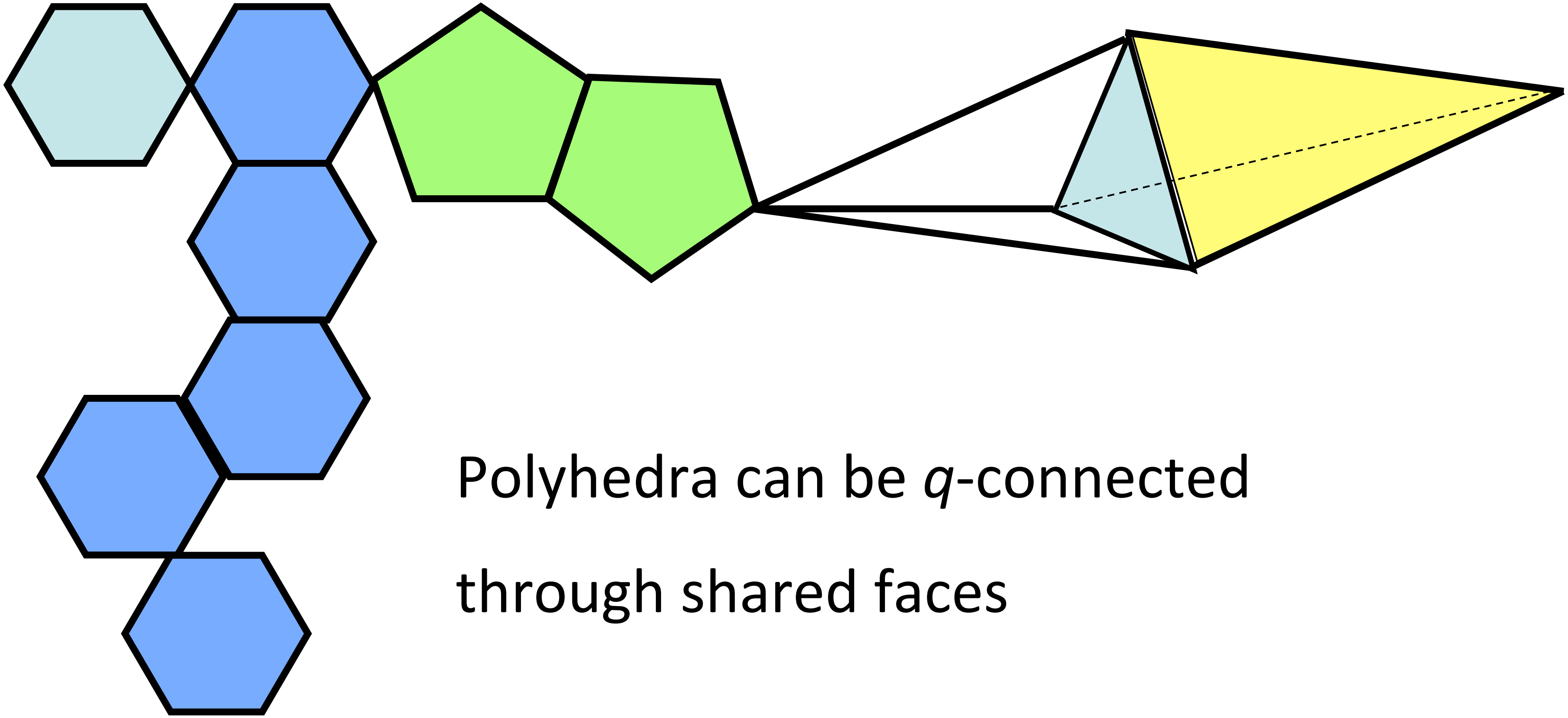


(a) 0-near (b) 1-near (c) 2-near



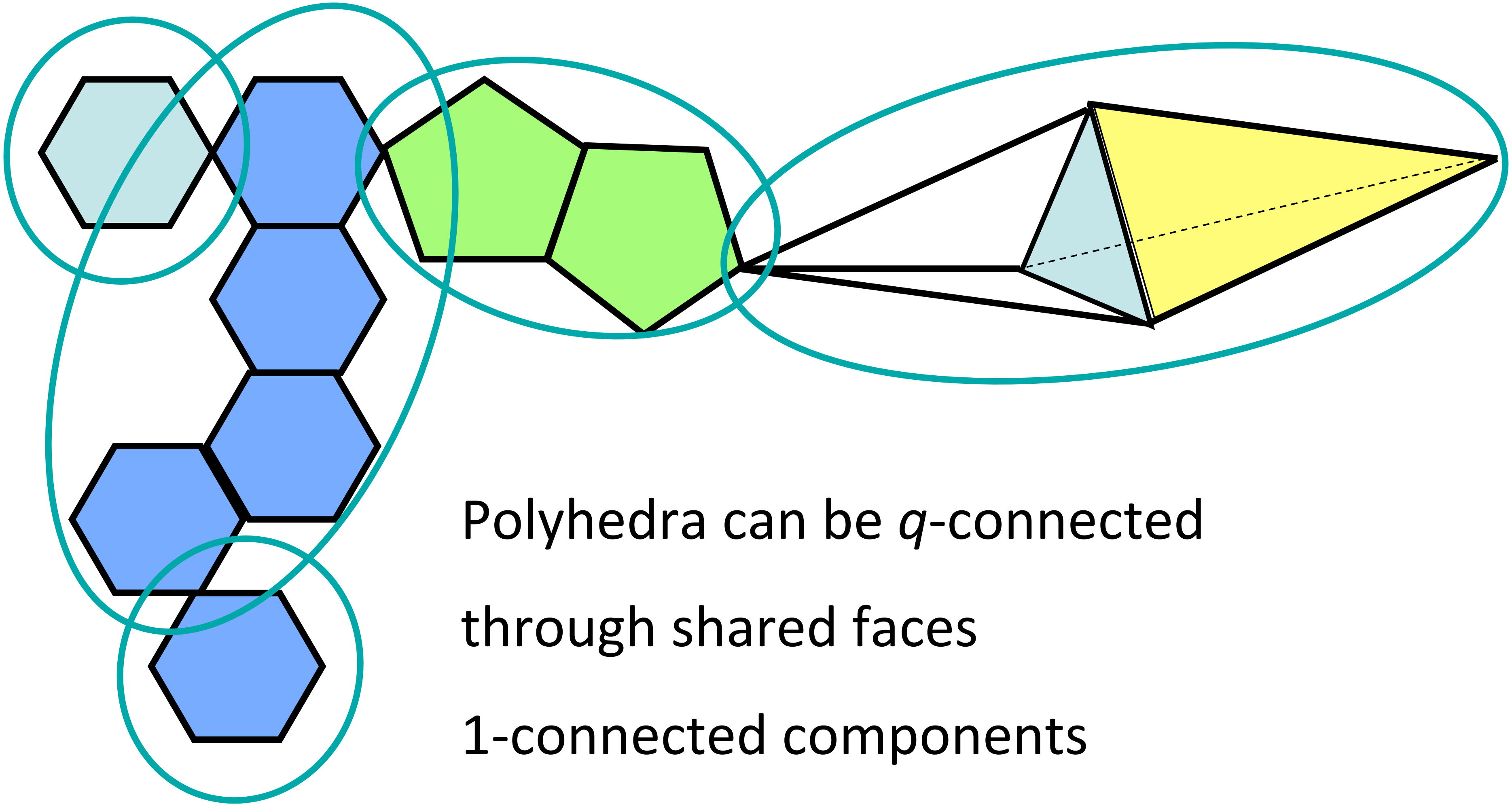
A network is a 1-dimensional simplicial complex with some 1-dimensional simplices (edges) connected through their 0-dimensional simplices (vertices)

Multidimensional Connectivity



Polyhedra can be *q*-connected through shared faces

Multidimensional Connectivity

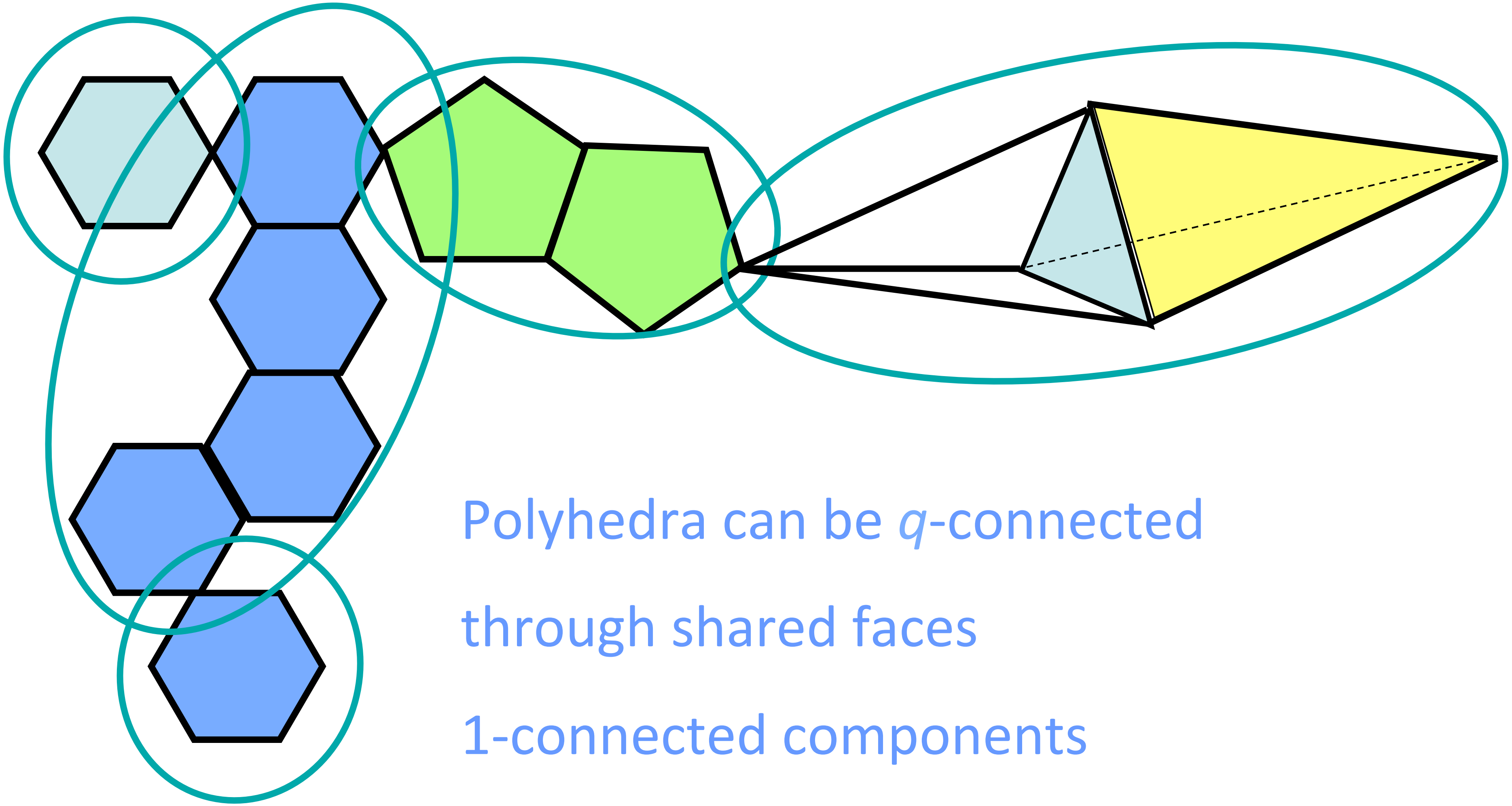


Polyhedra can be q-connected

through shared faces

1-connected components

Multidimensional Connectivity



Polyhedra can be *q*-connected

through shared faces

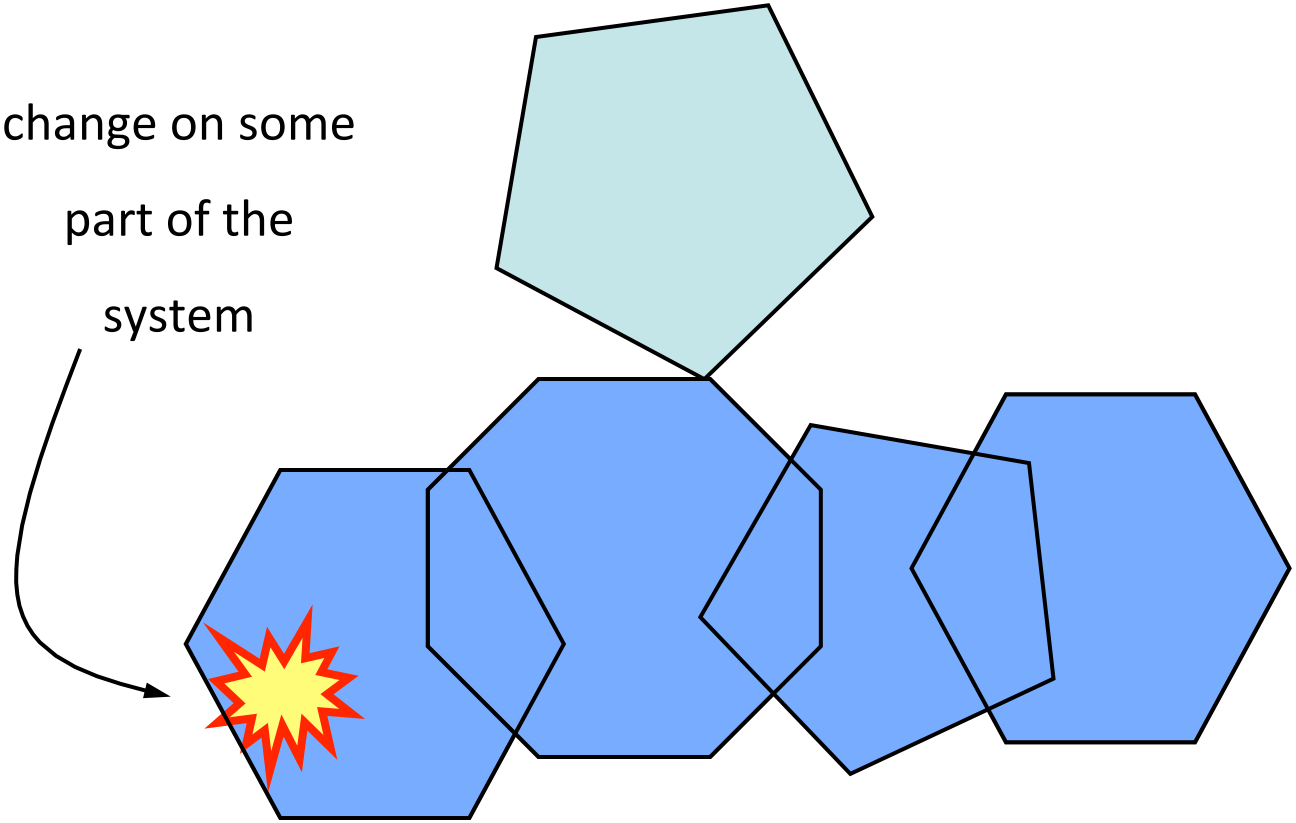
1-connected components

Q-analysis: listing q-components

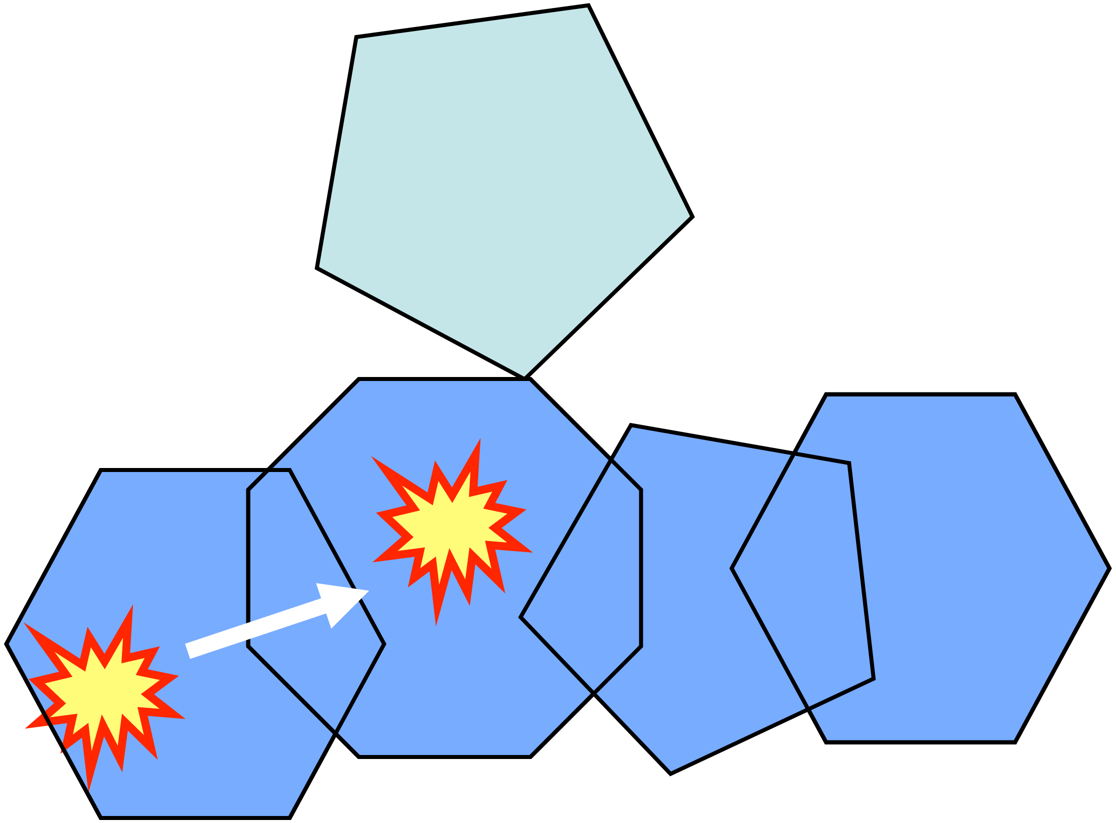
Polyhedral Connectivity & q-transmission

(q-percolation)

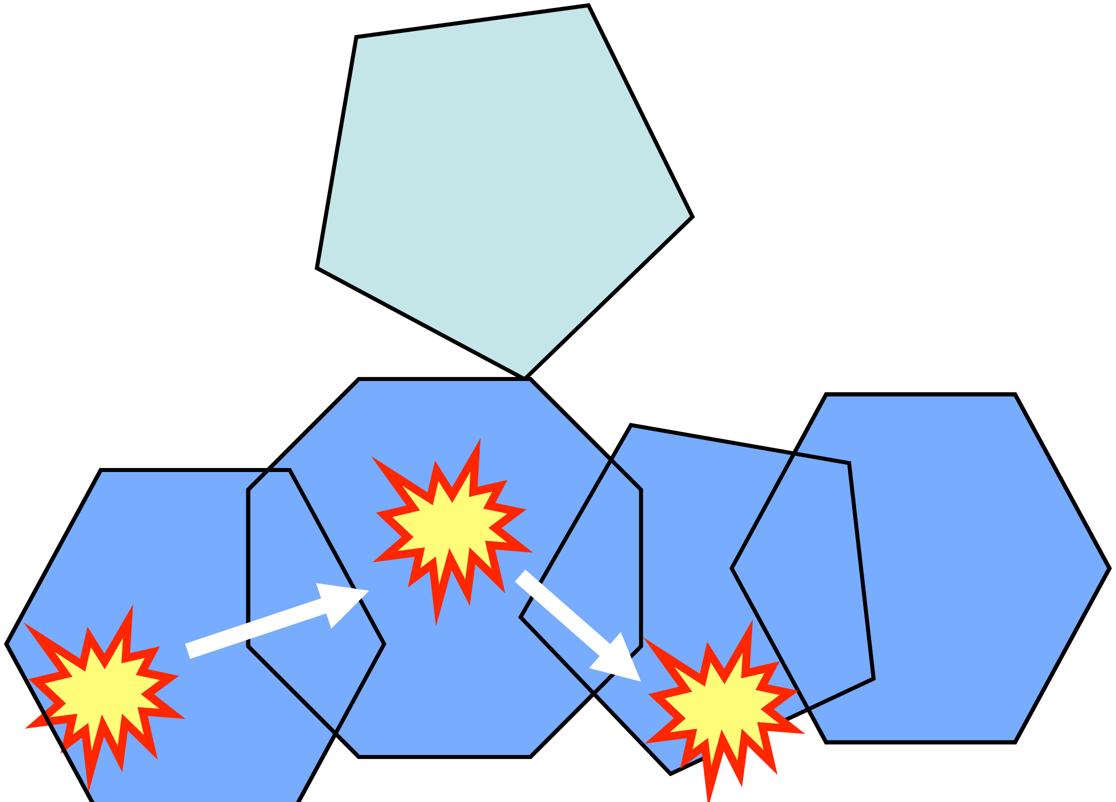
change on some
part of the
system



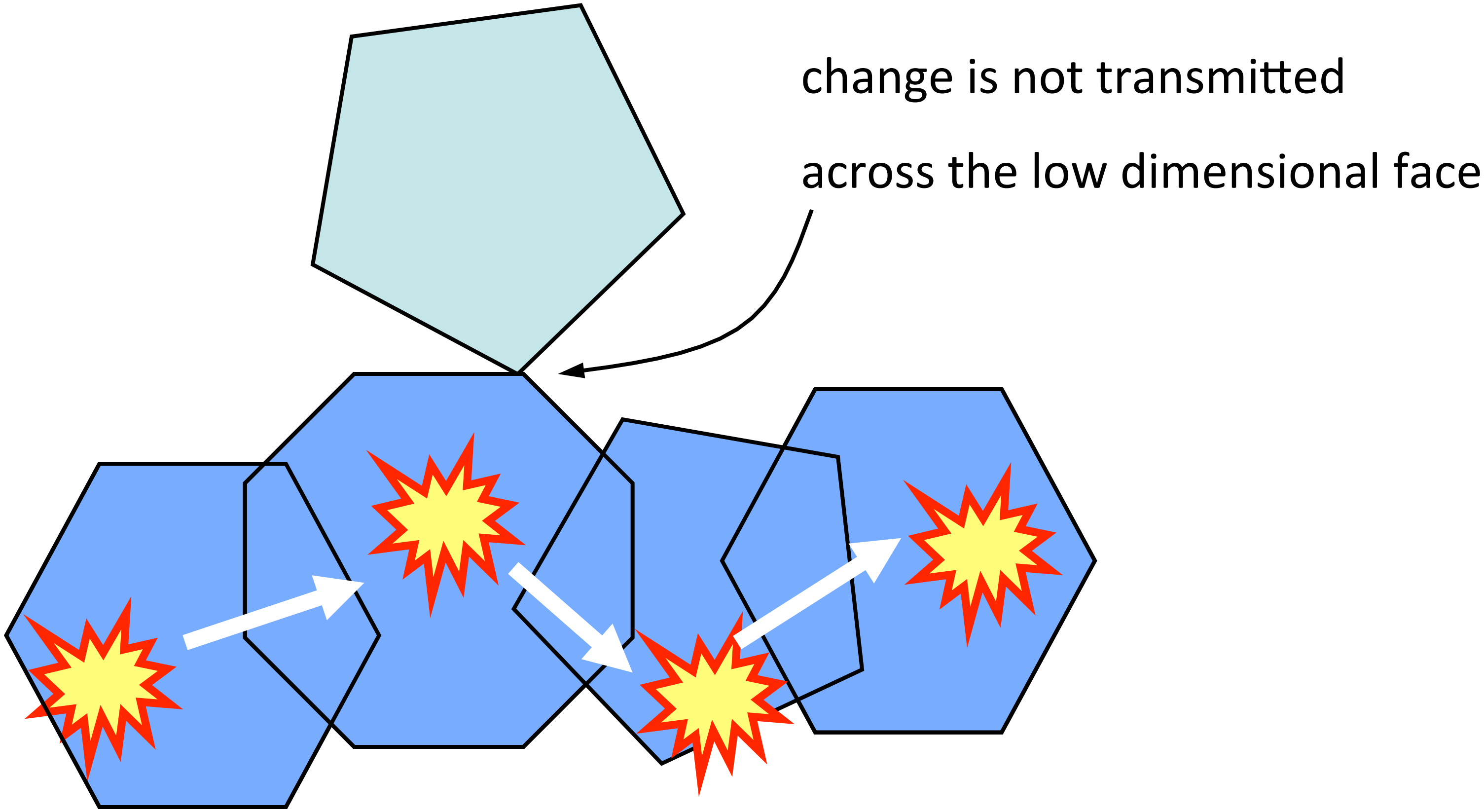
Polyhedral Connectivity & q-transmission



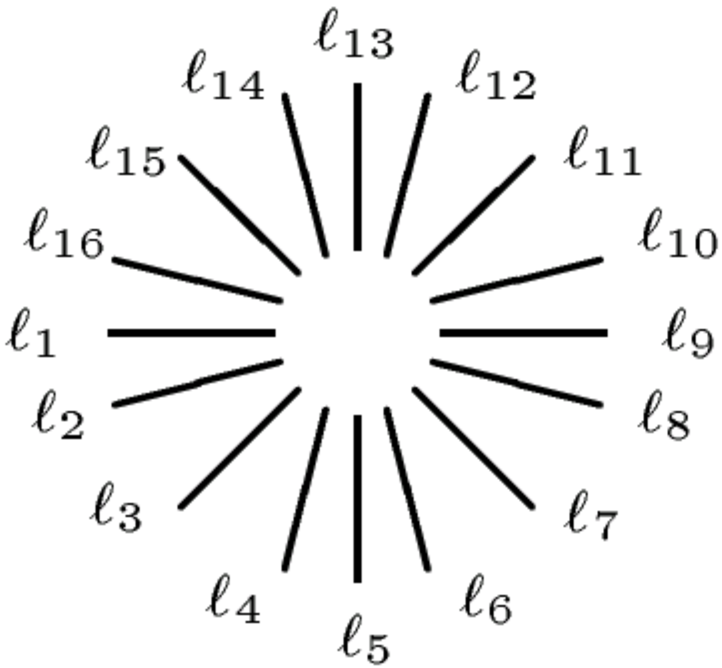
Polyhedral Connectivity & q-transmission



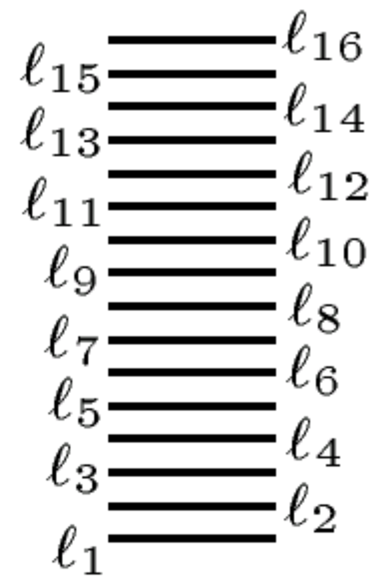
Polyhedral Connectivity & q-transmission



From Complexes to Hypernetworks



(a) The sun illusion
$\sigma_1 = \langle \ell_1, ..., \ell_{16}; R_1 \rangle$

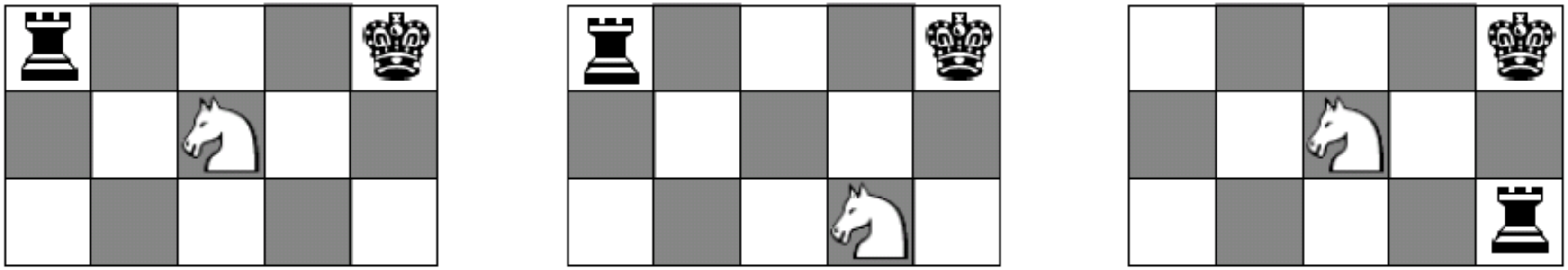


(b) the rectangle illusion
$\sigma_2 = \langle \ell_1, ..., \ell_{16}; R_2 \rangle$

Simplices are not rich enough to discriminate things

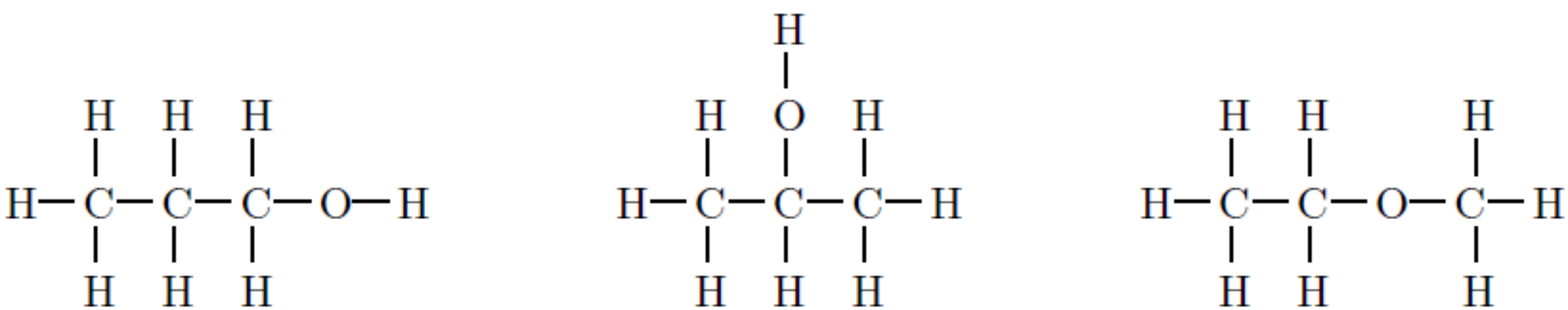
Same parts, different relation, different structure & emergence

We must have *relational simplices*



(a) ⟨rook, knight, king; R_1⟩ (b) ⟨rook, knight, king; R_2⟩ (c) ⟨rook, knight, king; R_3⟩

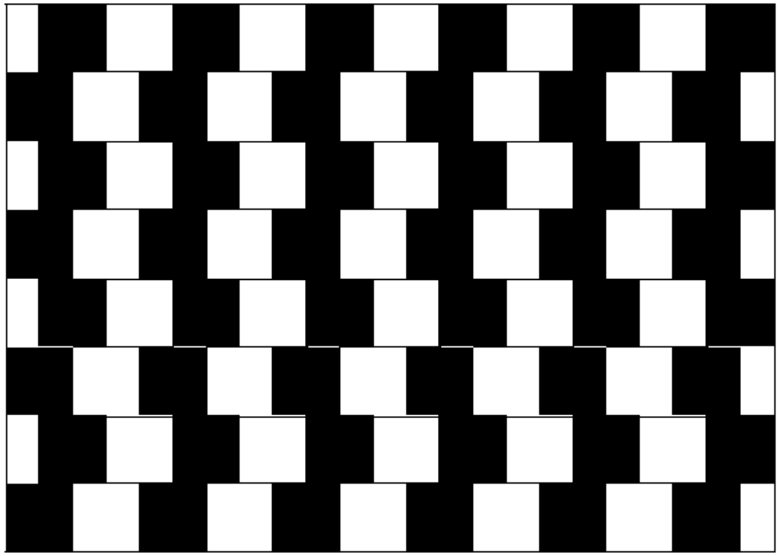
Fig. 6.5 The knight fork in chess



(a) n-propyl alcohol (b) isopropyl alcohol (c) methyl-ethyl-ether

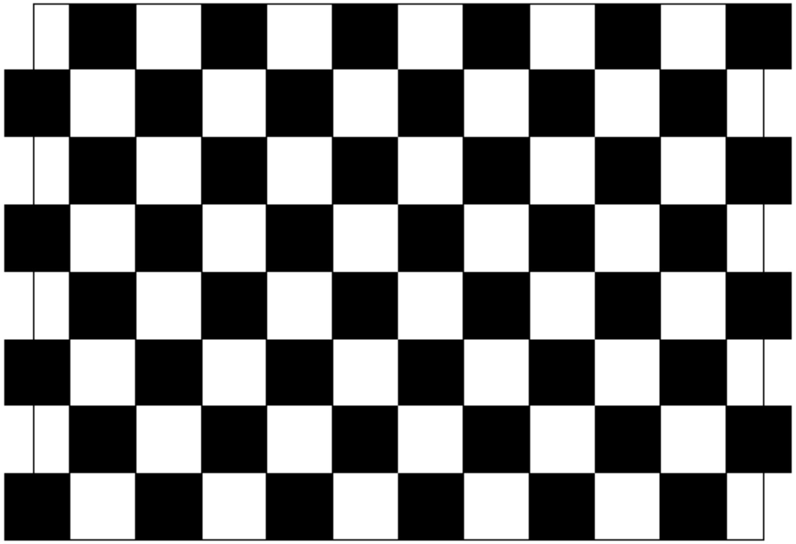
Fig. 6.6 Chemical isomers as relational simplices

Richard Gregory's café wall illusion



$\langle s_0, s_1, \ldots .s_{95}\ R_{offset} \rangle$

illusion: Squares narrow horizontally



$\langle s_0, s_1, \ldots .s_{95}\ R_{aligned} \rangle$

No illusion

A hypernetwork is a set of relational simplices

Hypernetworks augment and are consistent with all other network and hypergraph approaches to systems modelling:

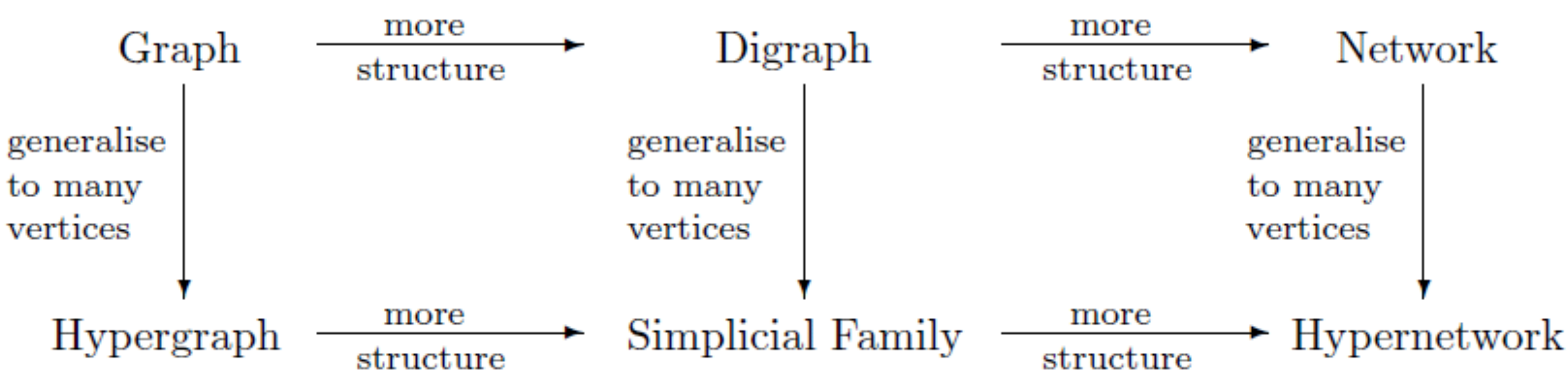
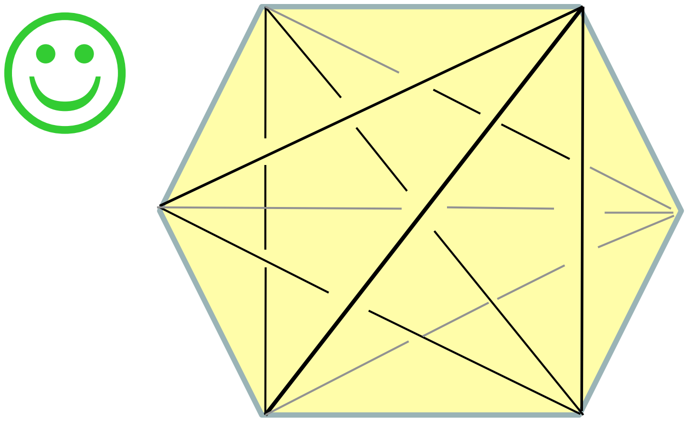


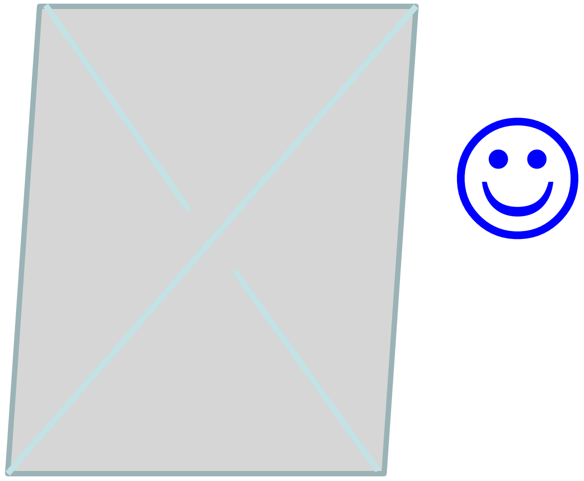
Fig. 6.1 Hypernetworks generalise all the common network structures

Hypernetworks and networks can & should work together

Dynamics on the hypernetwork backcloth

opinions

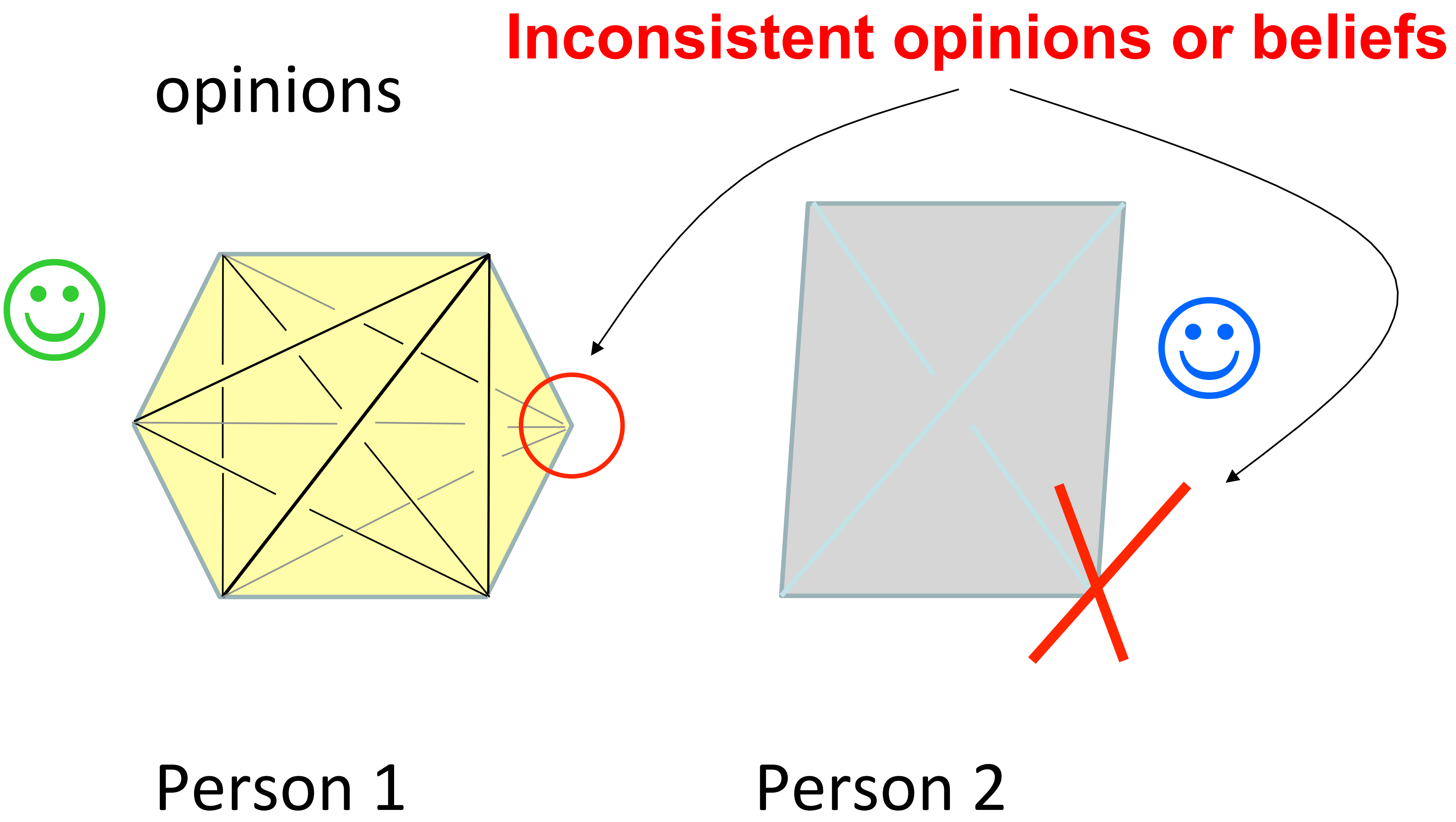




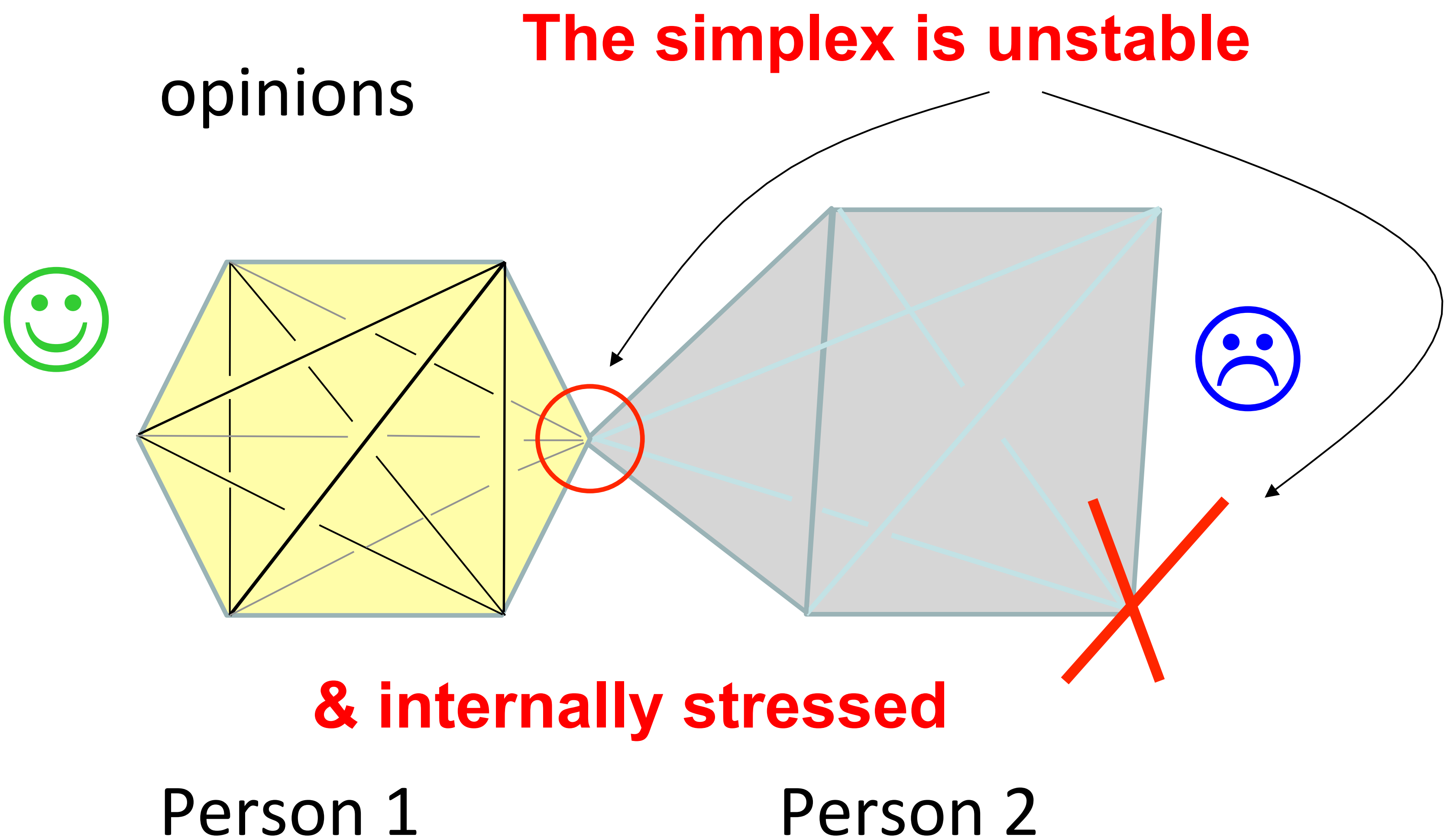
Person 1

Person 2

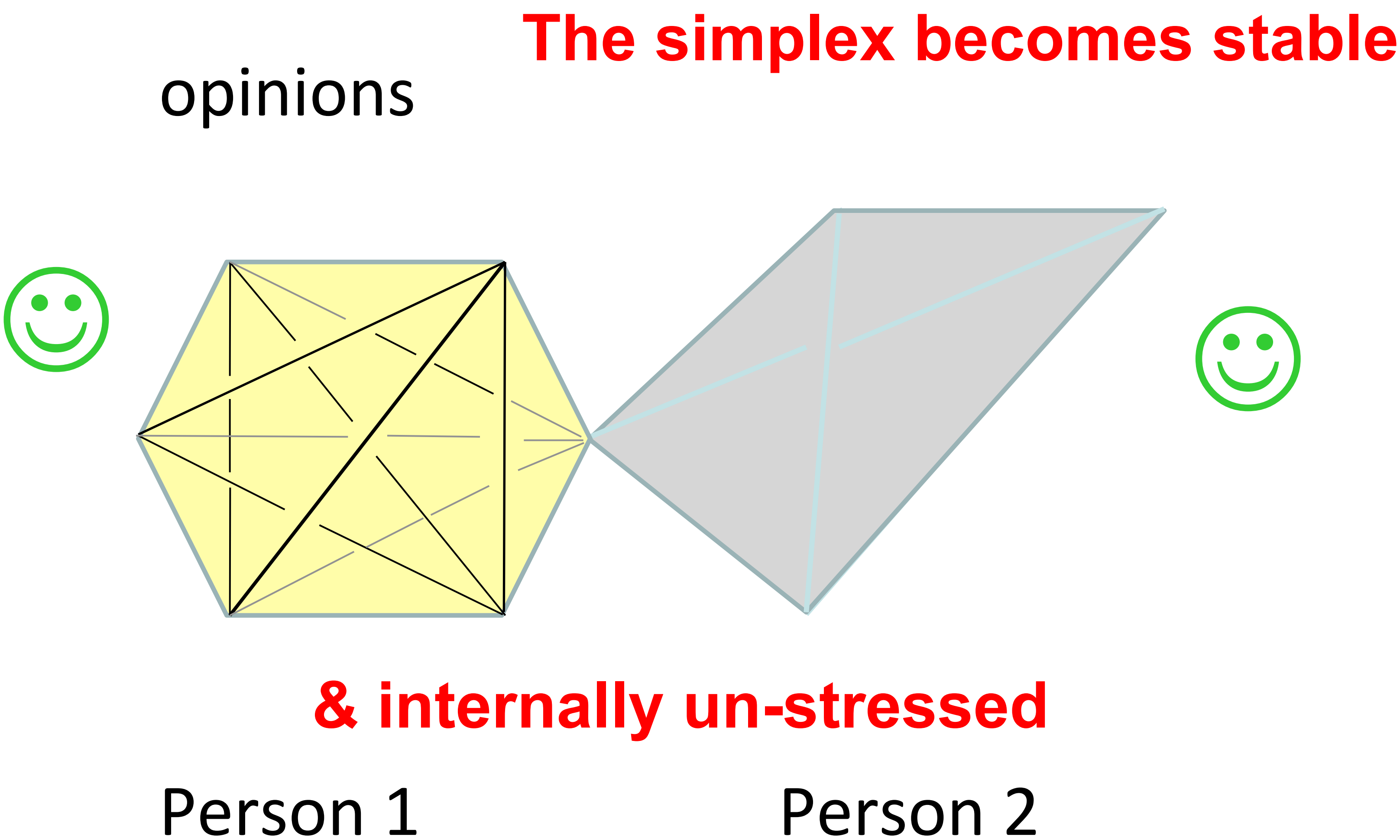
Dynamics on the hypernetwork backcloth



Dynamics on the hypernetwork backcloth



Dynamics on the hypernetwork backcloth



Relational Simplices and Multilevel Systems

5.1 Systems of Systems of Systems

Most systems are characterised by having many subsystems and levels of description. They are made up of inextricably entangled multilevel social and physical subsystems with intra-level and inter-level bottom-up and top-top-down dynamics. They are *systems of systems*. In fact they are systems of systems of systems, and more generally multiple levels of systems of systems.

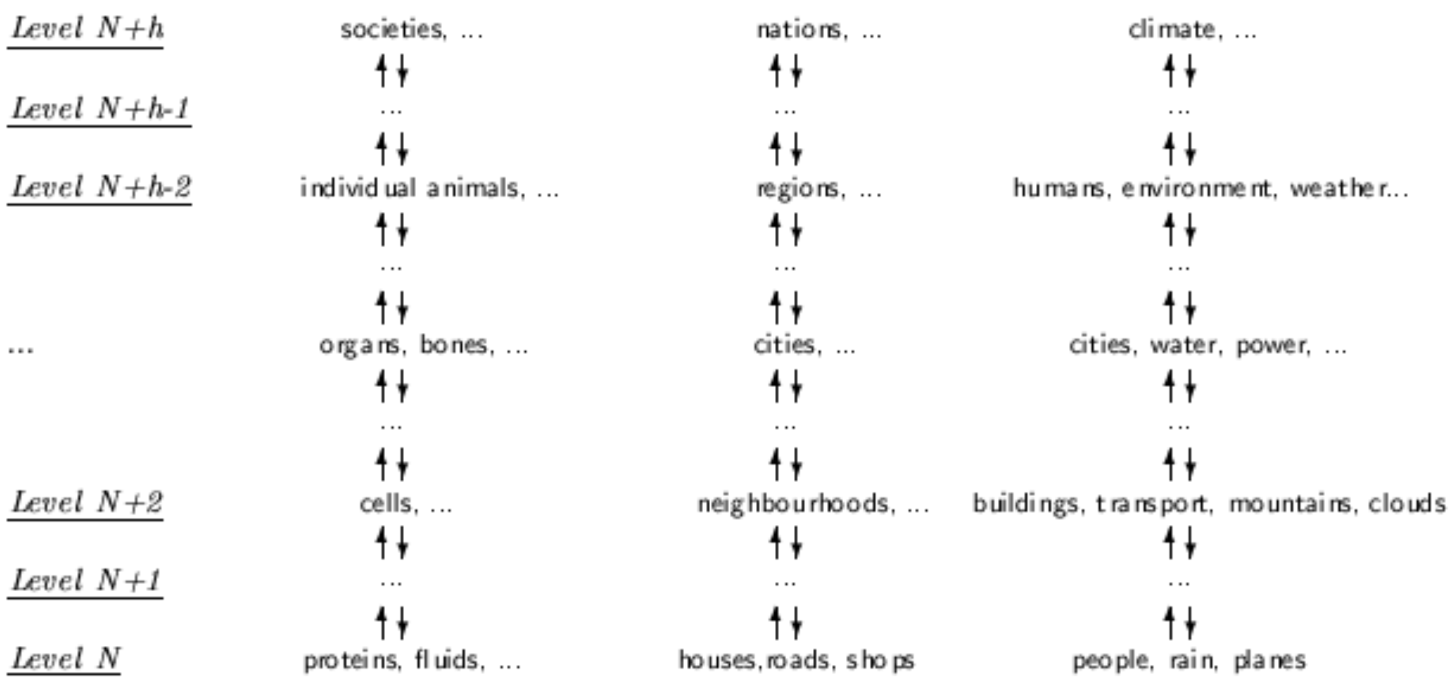
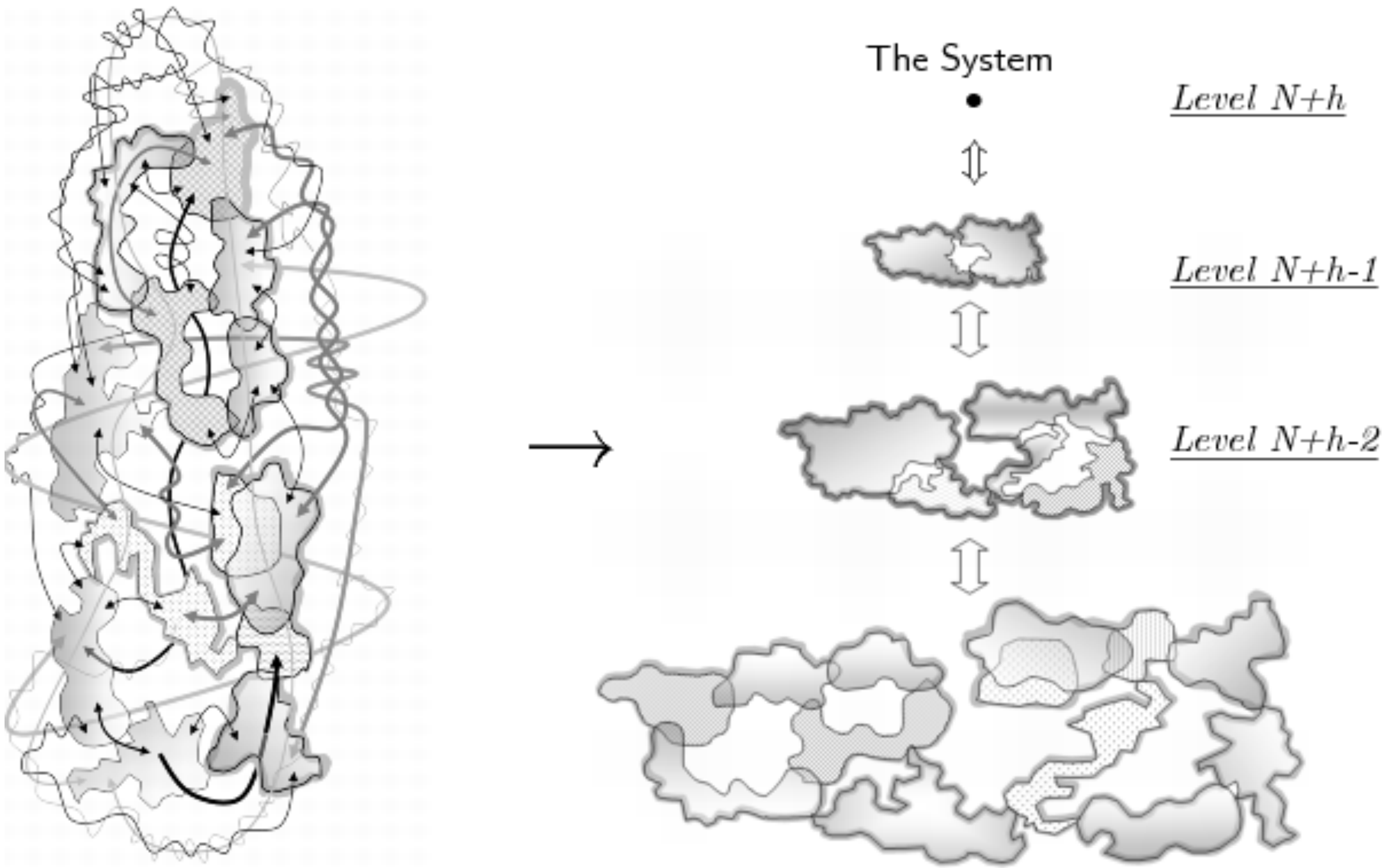


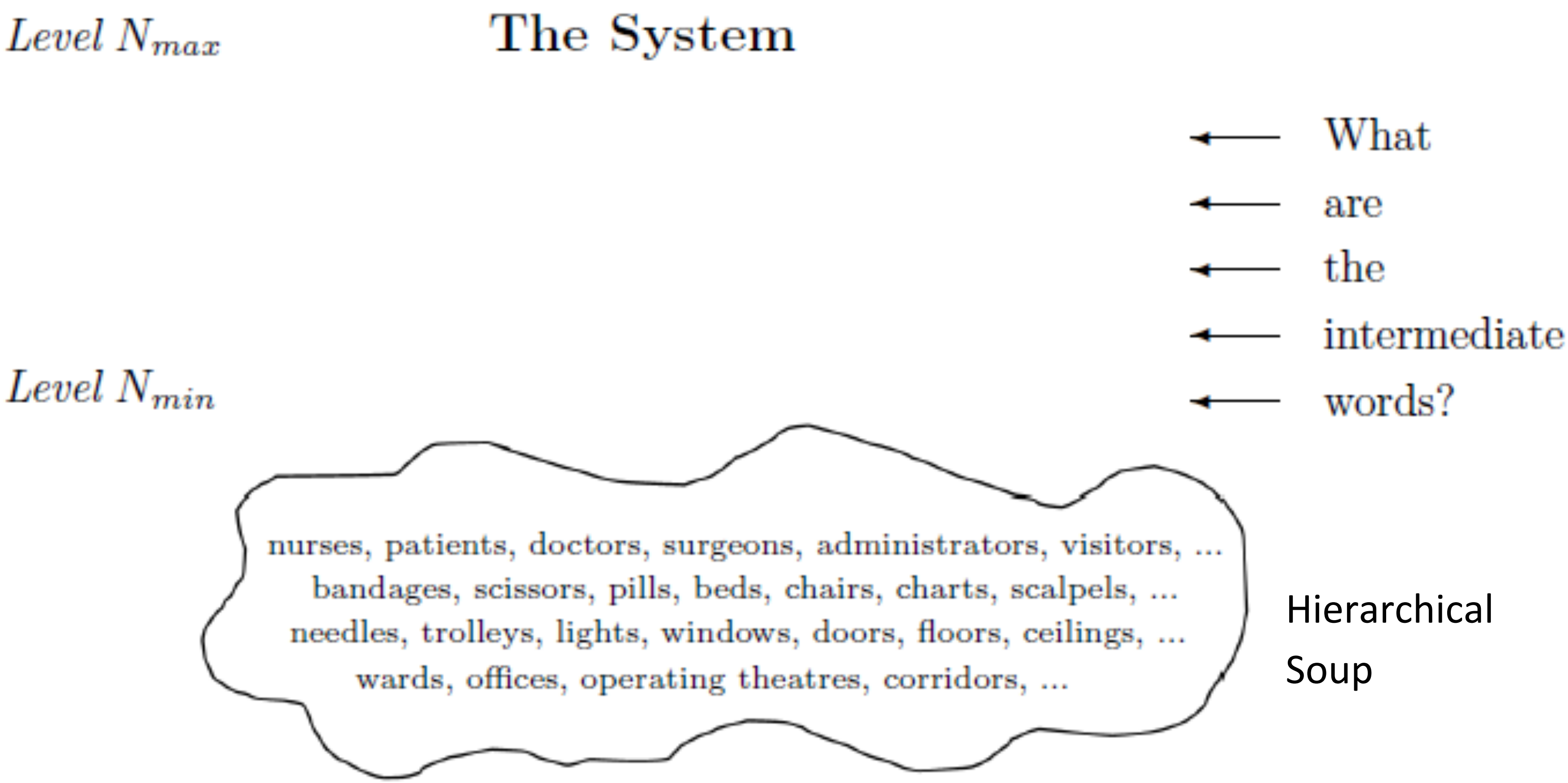
Fig. 5.1 Systems of systems of systems of systems ...

Multilevel Systems



Can highly entangled multilevel systems separated into well-defined levels ?

Multilevel Systems



The Intermediate Word Problem

Multilevel Systems

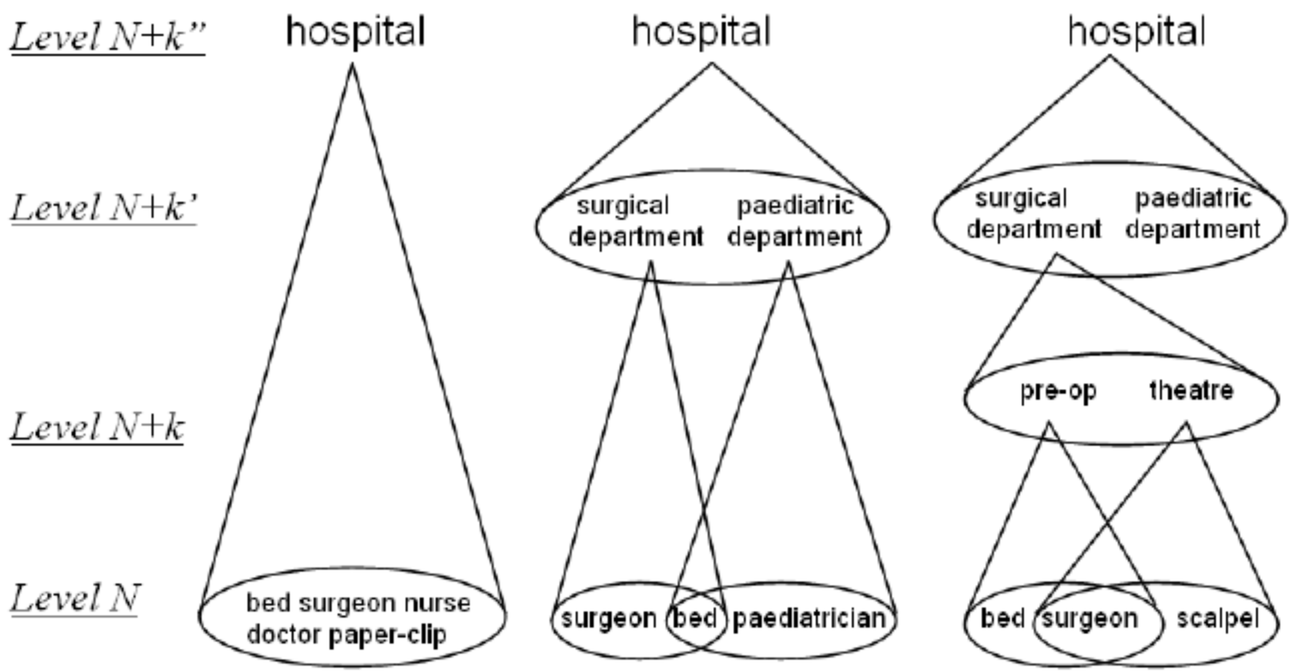
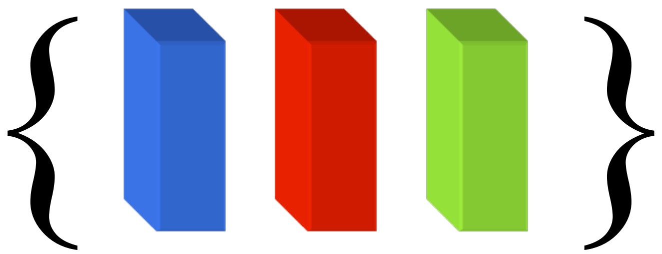


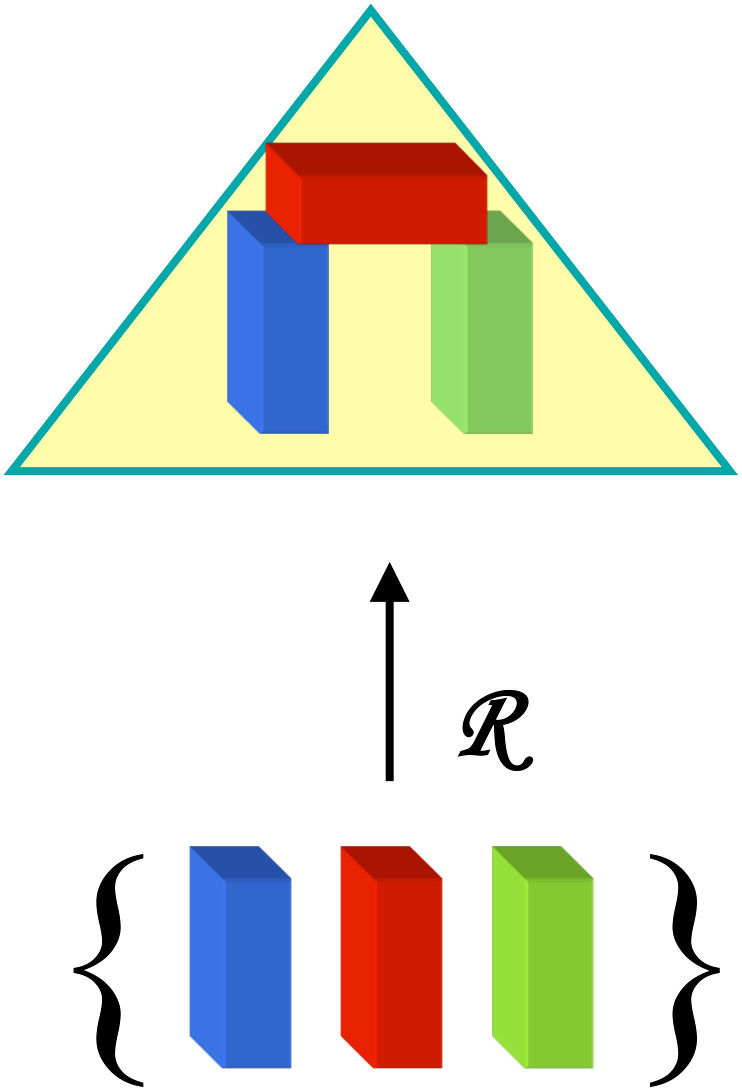
Fig. 5.4 Intermediate Words for a Hospital System

Formation of simplices ⇒ hierarchical structure

e.g. take a set of 3 blocks

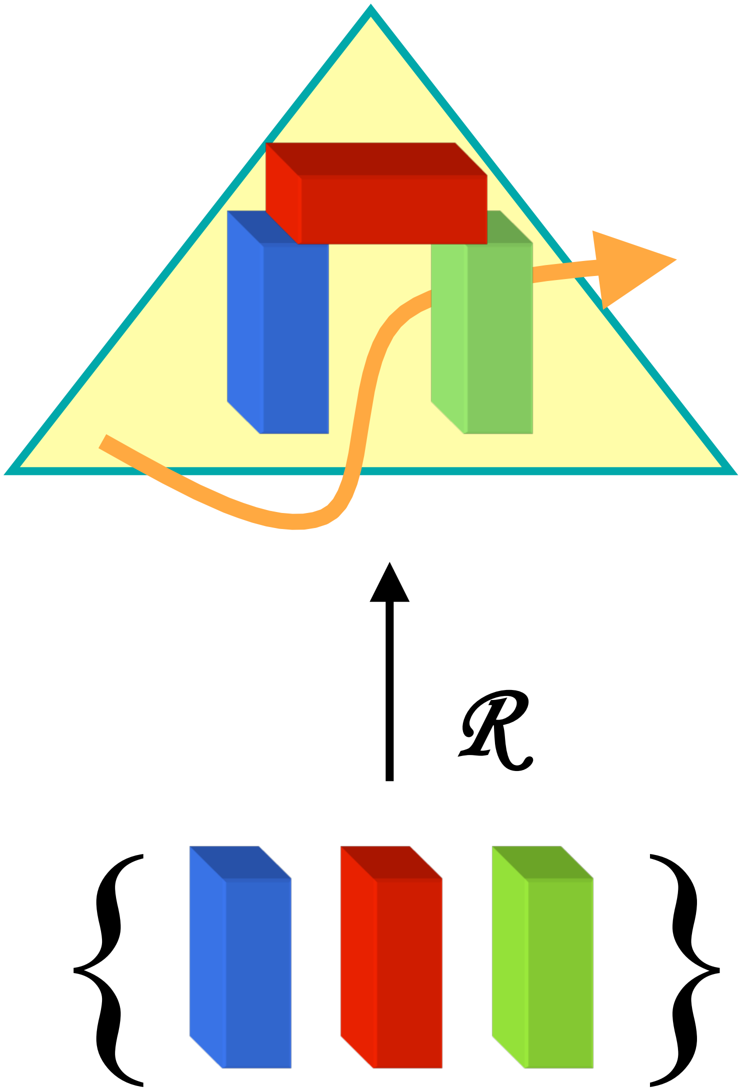


Formation of simplices ⟹ hierarchical structure



e.g. take a set of 3 blocks assembled by a 3-ary relation $\mathcal{R}$

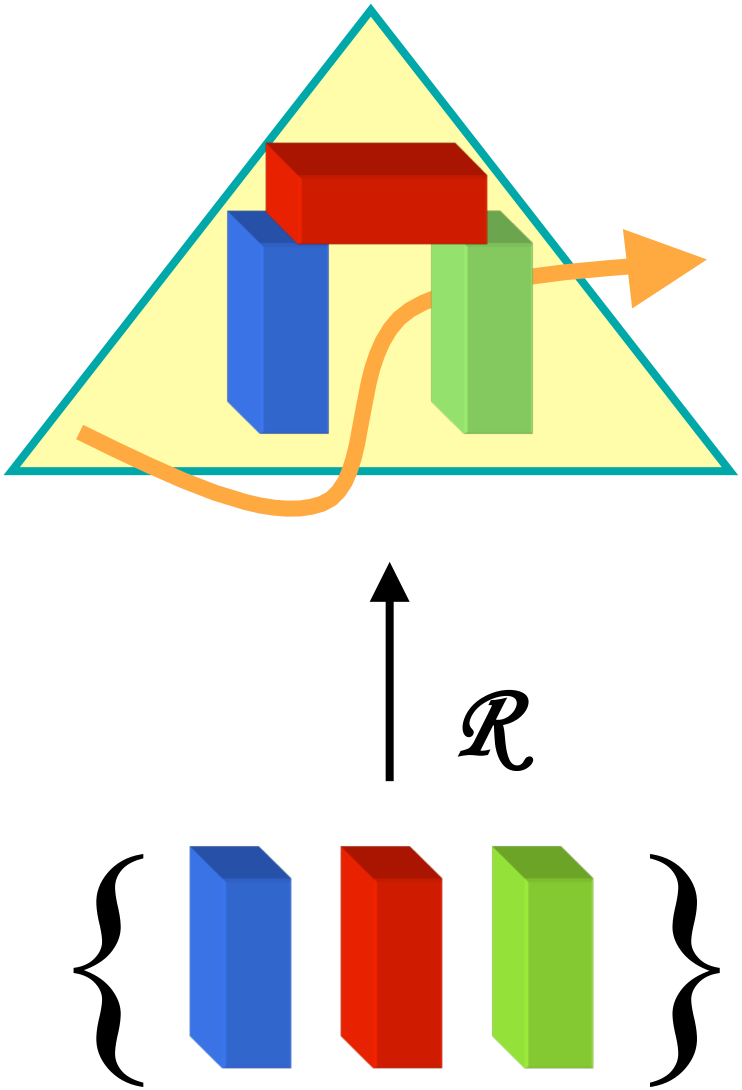
Formation of simplices ⇒ hierarchical structure



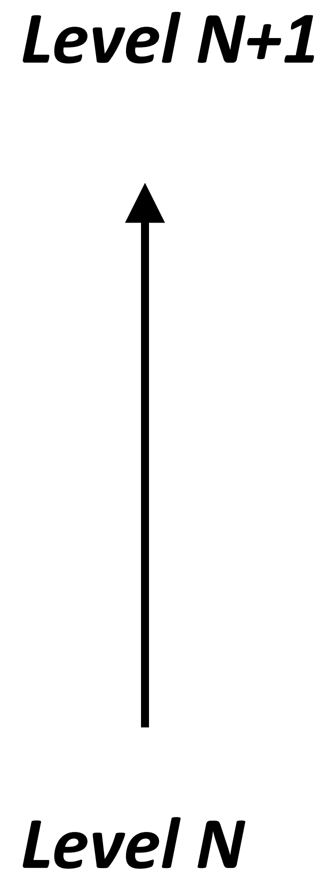
e.g. take a set of 3 blocks assembled by a 3-ary relation $\mathcal{R}$

The structure has an **emergent property**

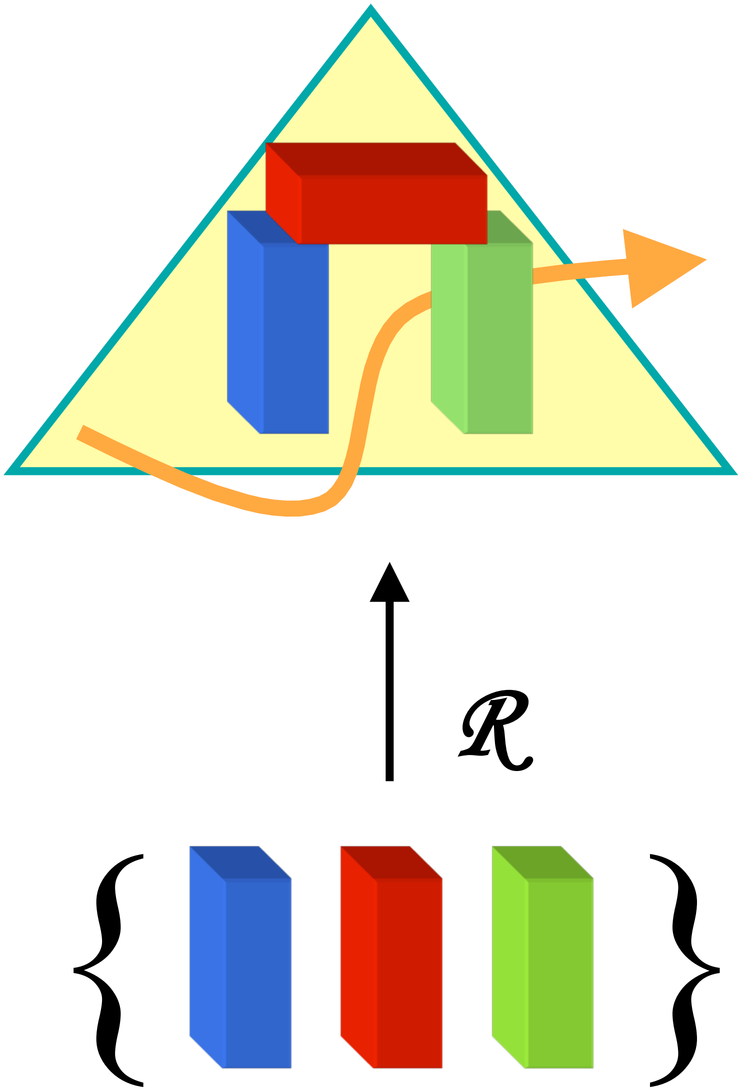
Formation of simplices ⇒ hierarchical structure



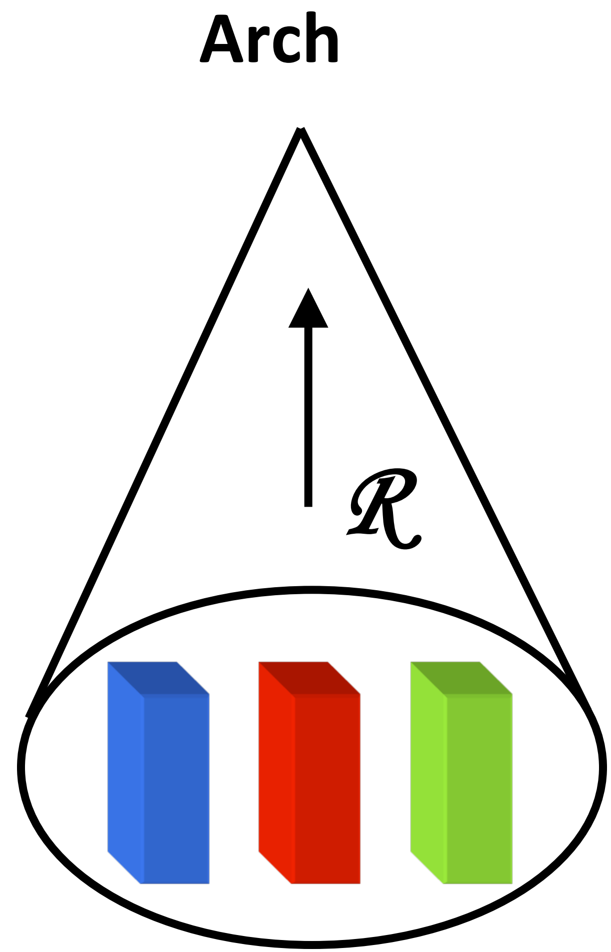
n-ary
relation
assembles
elements
into named
structures at
a higher
level



Formation of simplices ⇒ hierarchical structure



n-ary relation assembles elements into named structures at a higher level



AND and OR aggregations in multilevel systems

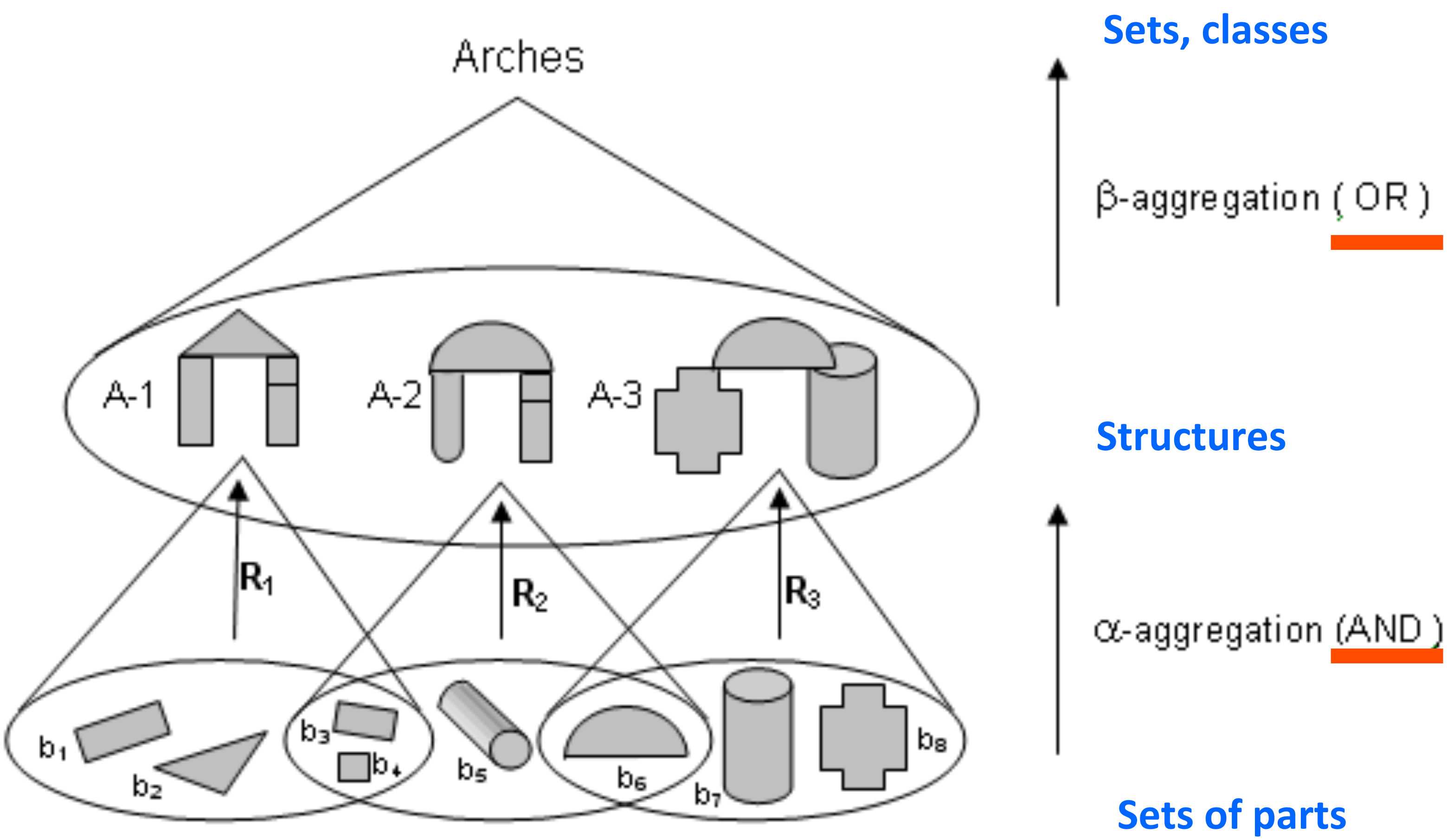


Figure 8. Two different types of multilevel aggregation

Conventional classification trees don't have alpha aggregations

Mereology

Parts and wholes go back millennia to Plato and Aristotle.

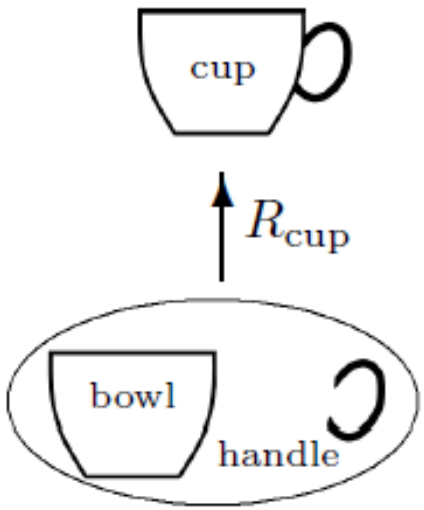
mereology was coined in 1927 by Stanislaw Lesniewski

A *mereological system* is defined to be composed of objects, *X*, and a binary relation called ***parthood***, '*x* is a part of *y*'.

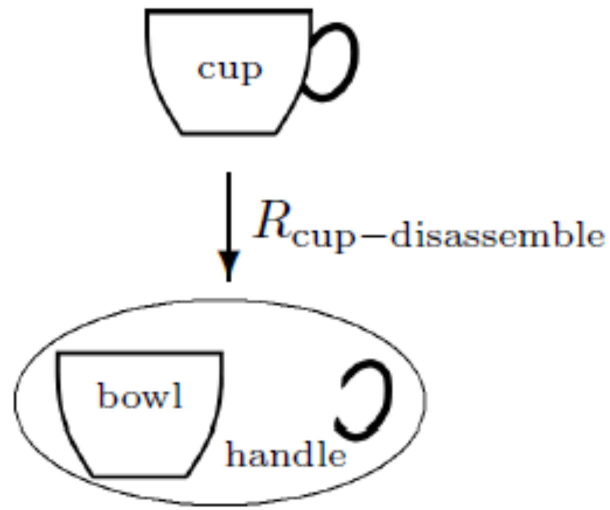
Winston, Chaffin and Herrmann gave six types of meronymic relations:

1. component integral object (pedal-bike),
2. member-collection (ship-fleet),
3. portion-mass (slice-pie),
4. stuff-object (steel-car),
5. feature-activity (paying-shopping), and
6. place-area (Everglades-Florida).

Mereology: e.g. component – integral object



(a) The handle and bowl R_{cup}-assemble into a cup

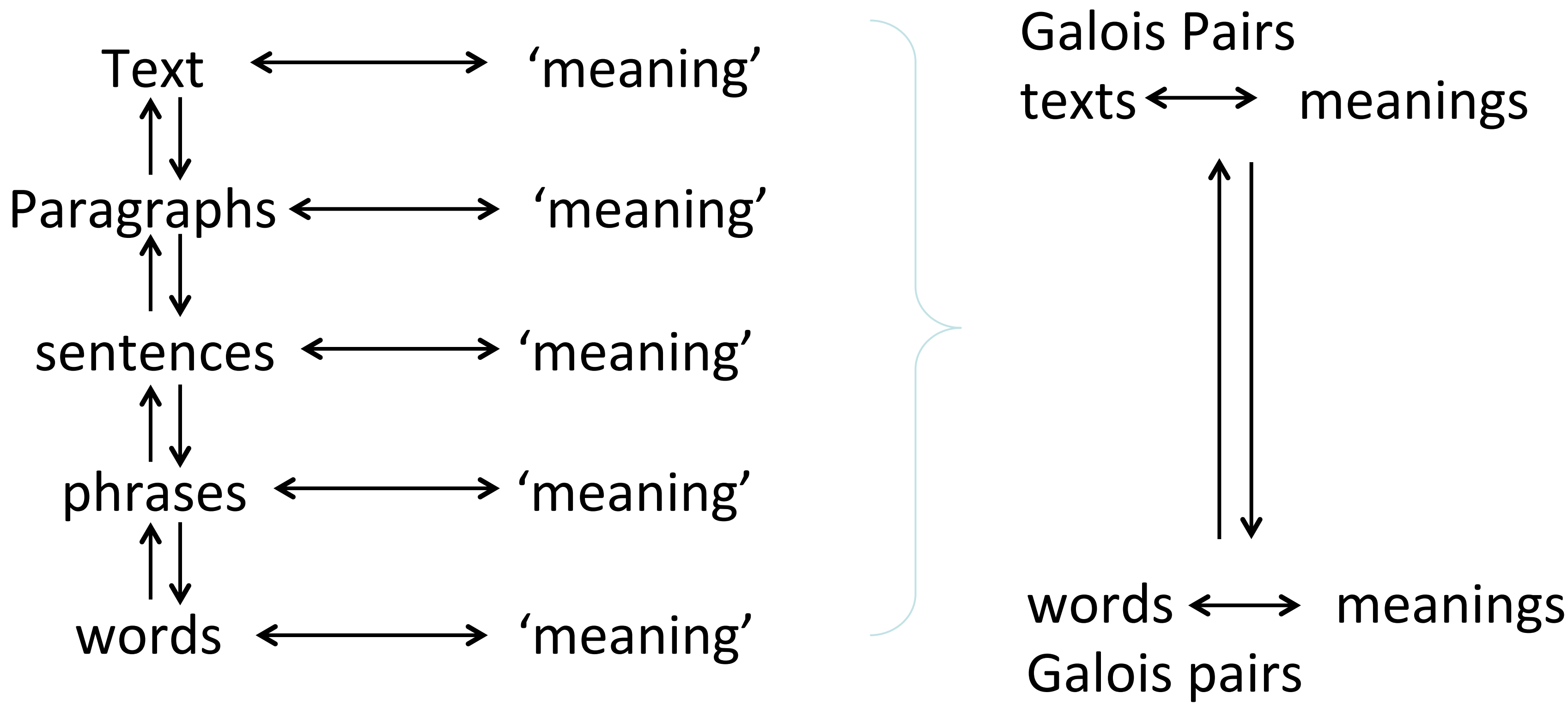


(b) The cup is (mentally)disassembled under $R_{\text{cup-disassemble}}$ into a handle and a bowl

Fig. 1.21 The handle is part of the cup

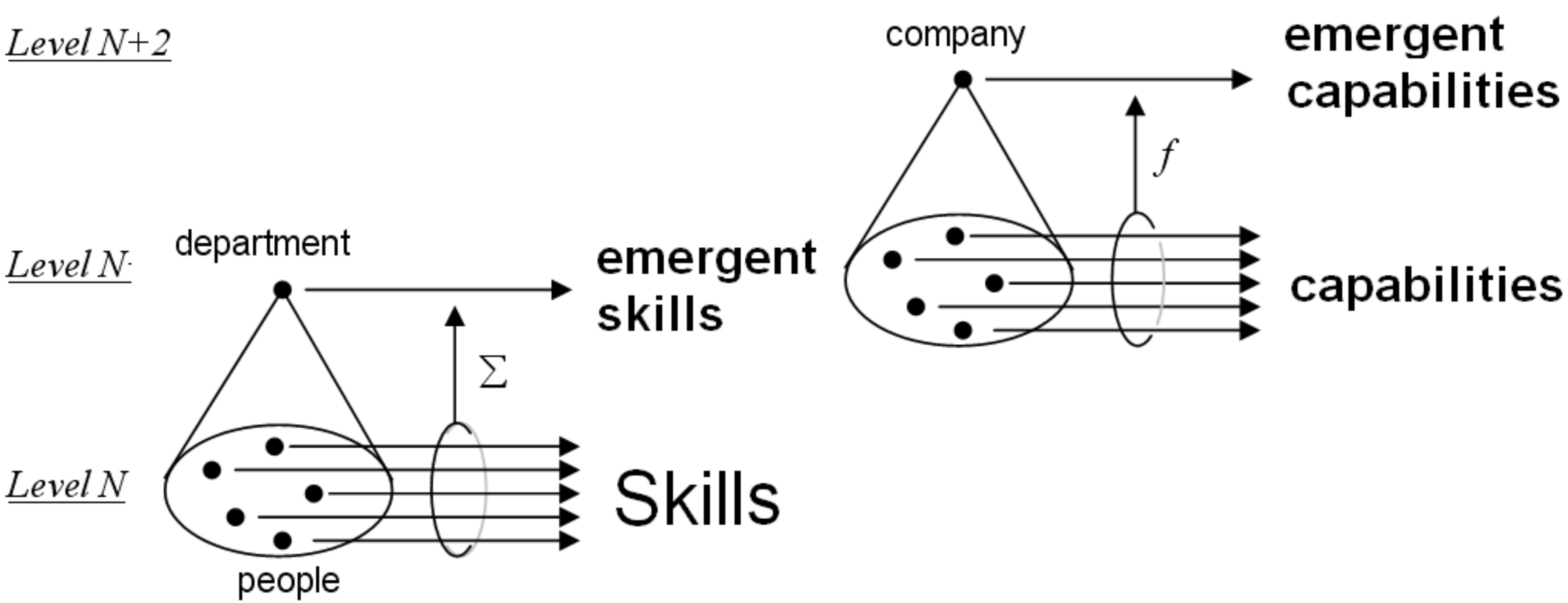
Applications

Digital texts are multilevel systems of hypersimplices



Applies to the analysis of policy narrative in Big Data – but may need many relations

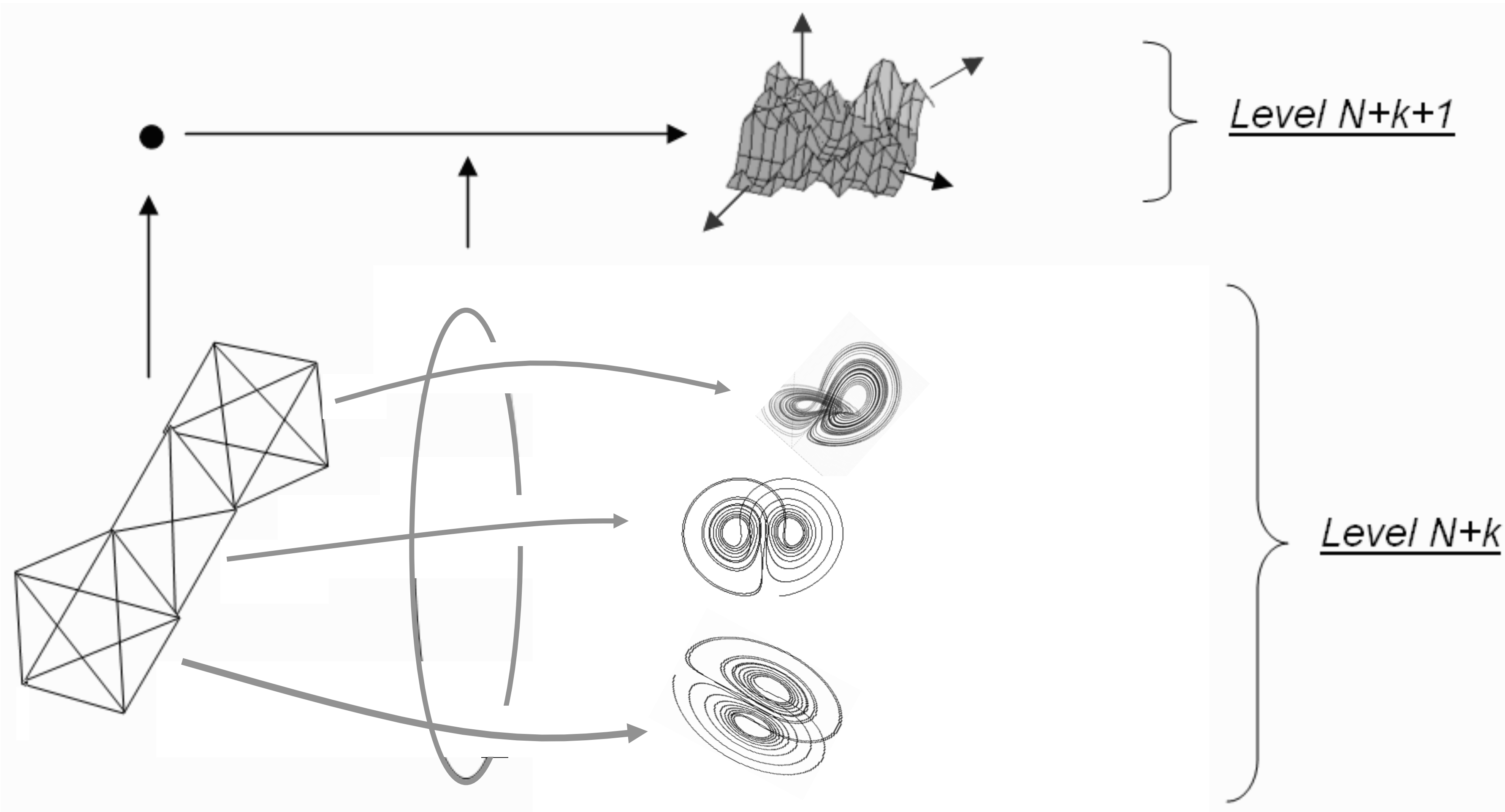
Multilevel patterns of numbers on the structure



The simplices form a backcloth for the more dynamic traffic (numbers)

… but there are also backcloth dynamics as relational simplices are formed.

Dynamics on the hypernetwork backcloth



System dynamics as traffic on a fixed multilevel backcloth

e.g. the dynamics of greenhouse gas reduction

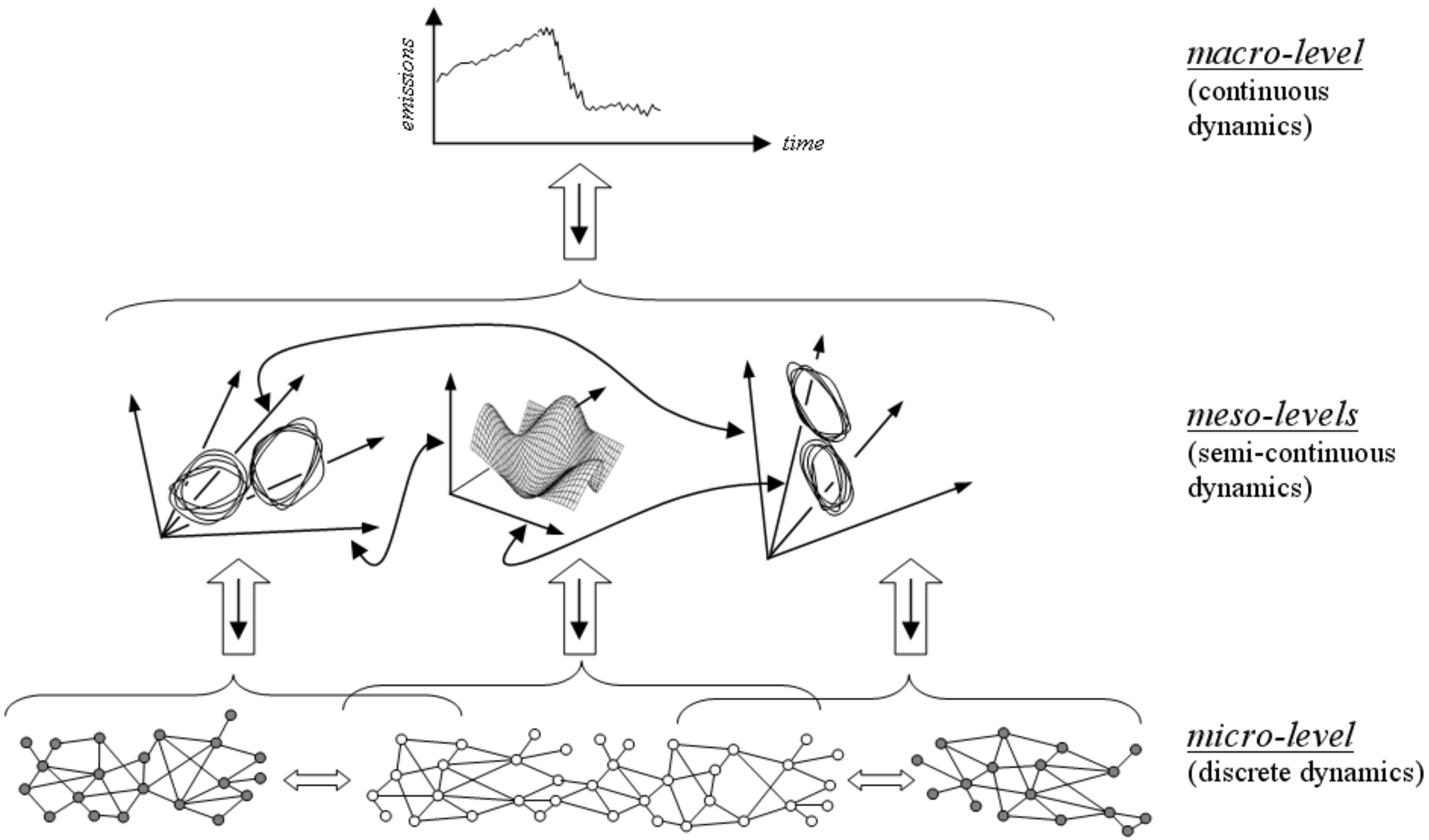
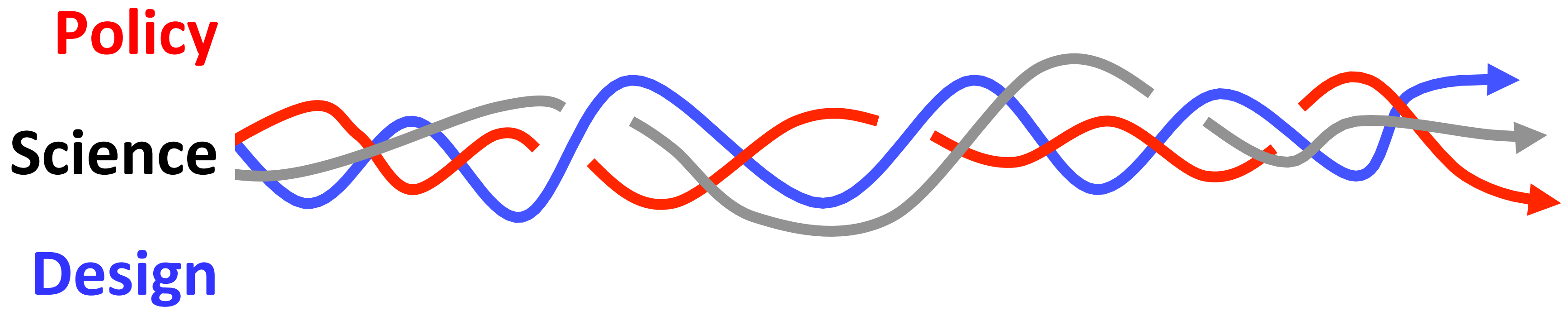


Figure 2. discrete micro-dynamic, semi-continuous meso-dynamics and continuous macro-dynamic

3. Policy

Policy is designing the future

Policy as designing the future is *entangled* with complexity science and design



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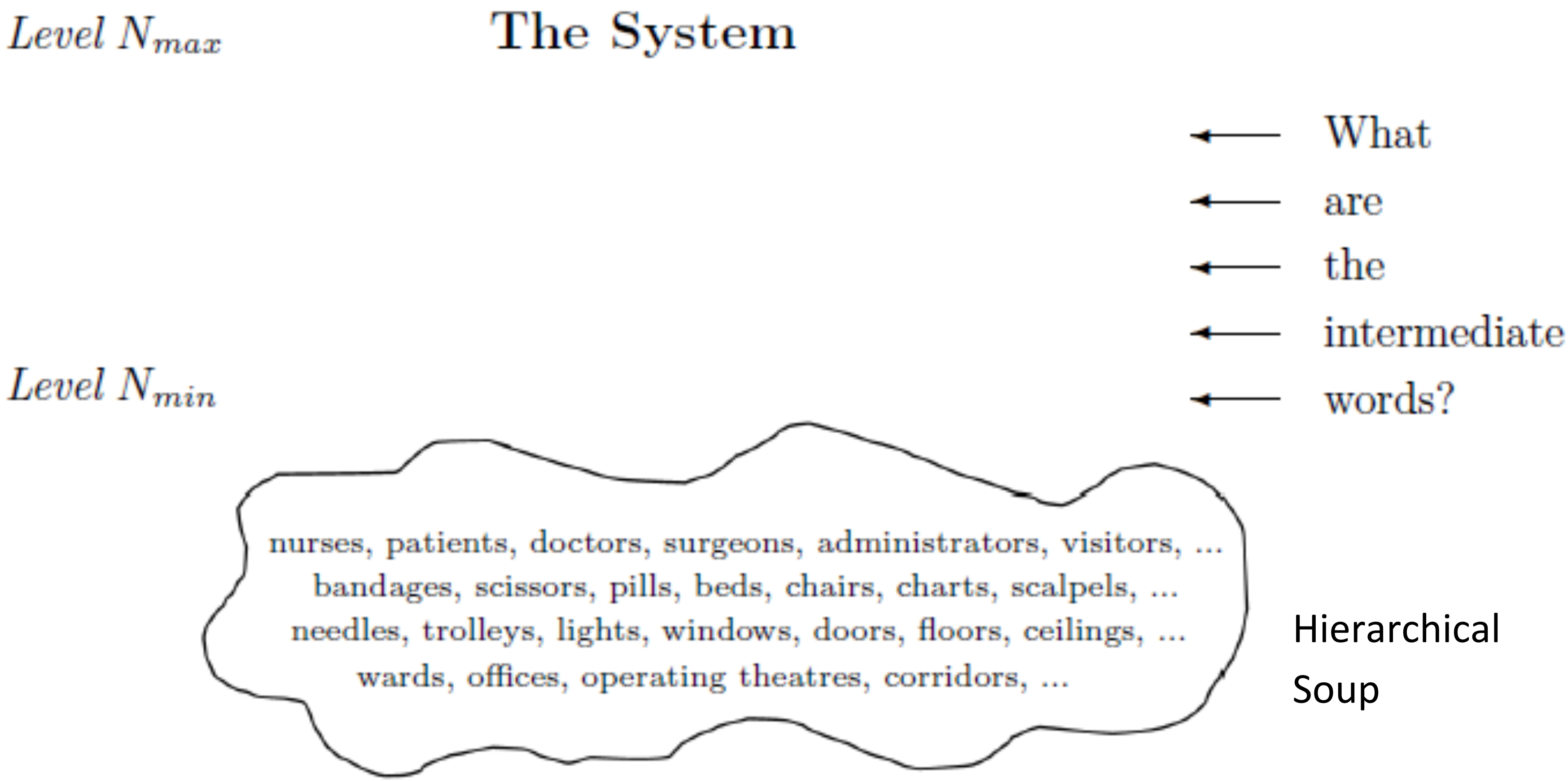


Design is an Intermediate Word Problem

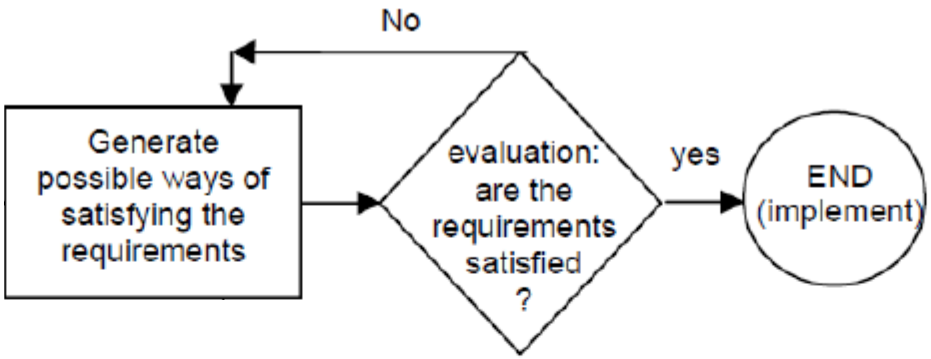
What are the intermediate structures ?

What shall we call them ?

Policy is designing the future

Innovation involves creating artificial systems

Creating artificial systems involves **Design**



The simplified generate-evaluate model of the design process

Policy is designing the future

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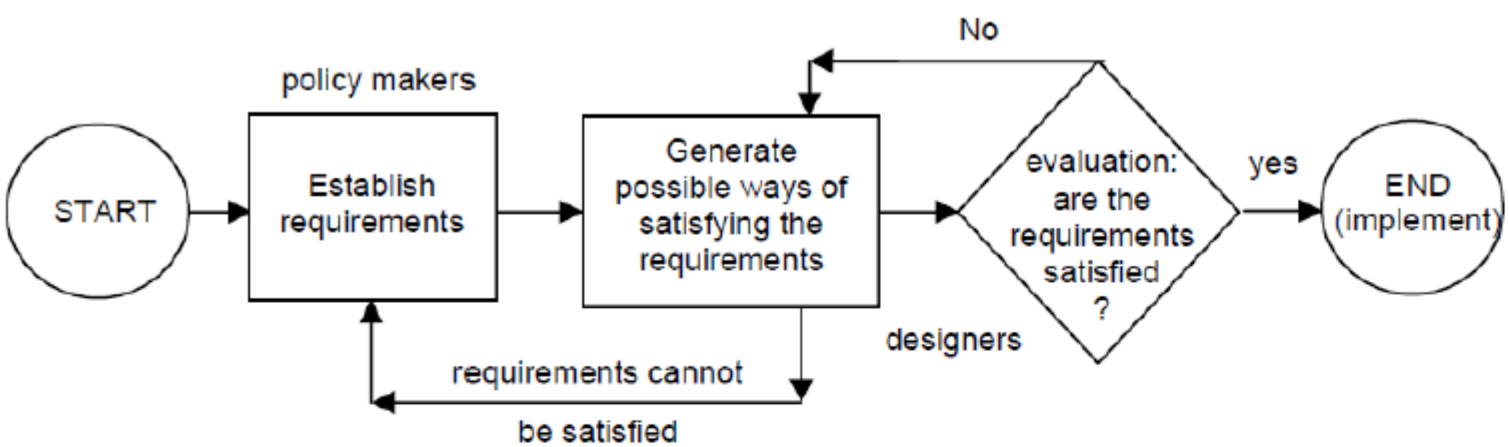


Fig. 1 The simplified requirements-generate-evaluate model of the design process

Design a co-evolution between what you think
you want & what you think you can have

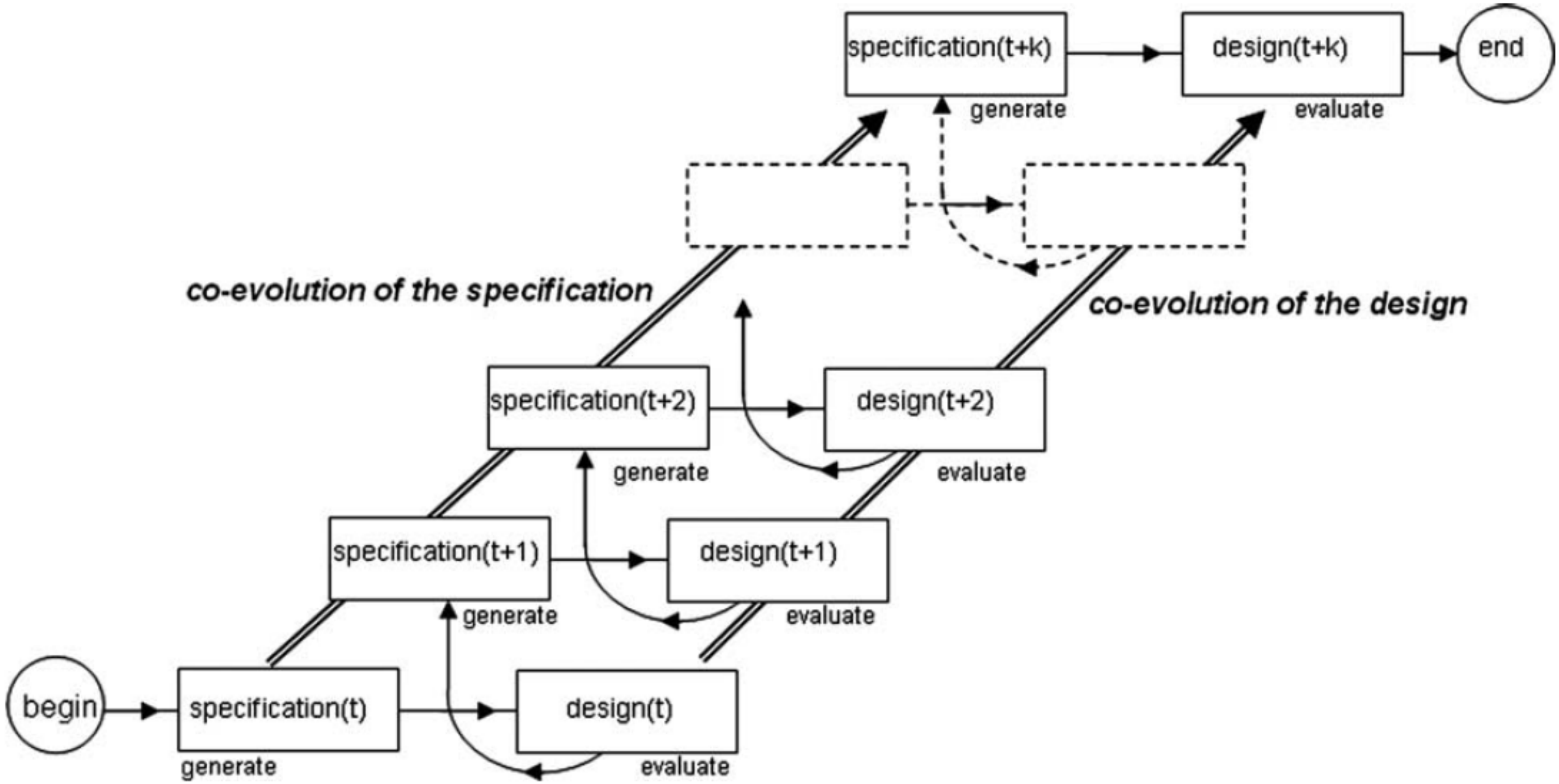


Fig 2. The co-evolution between specification and design through a generate–evaluate spiral.

Design is an iterative *process* – it takes time

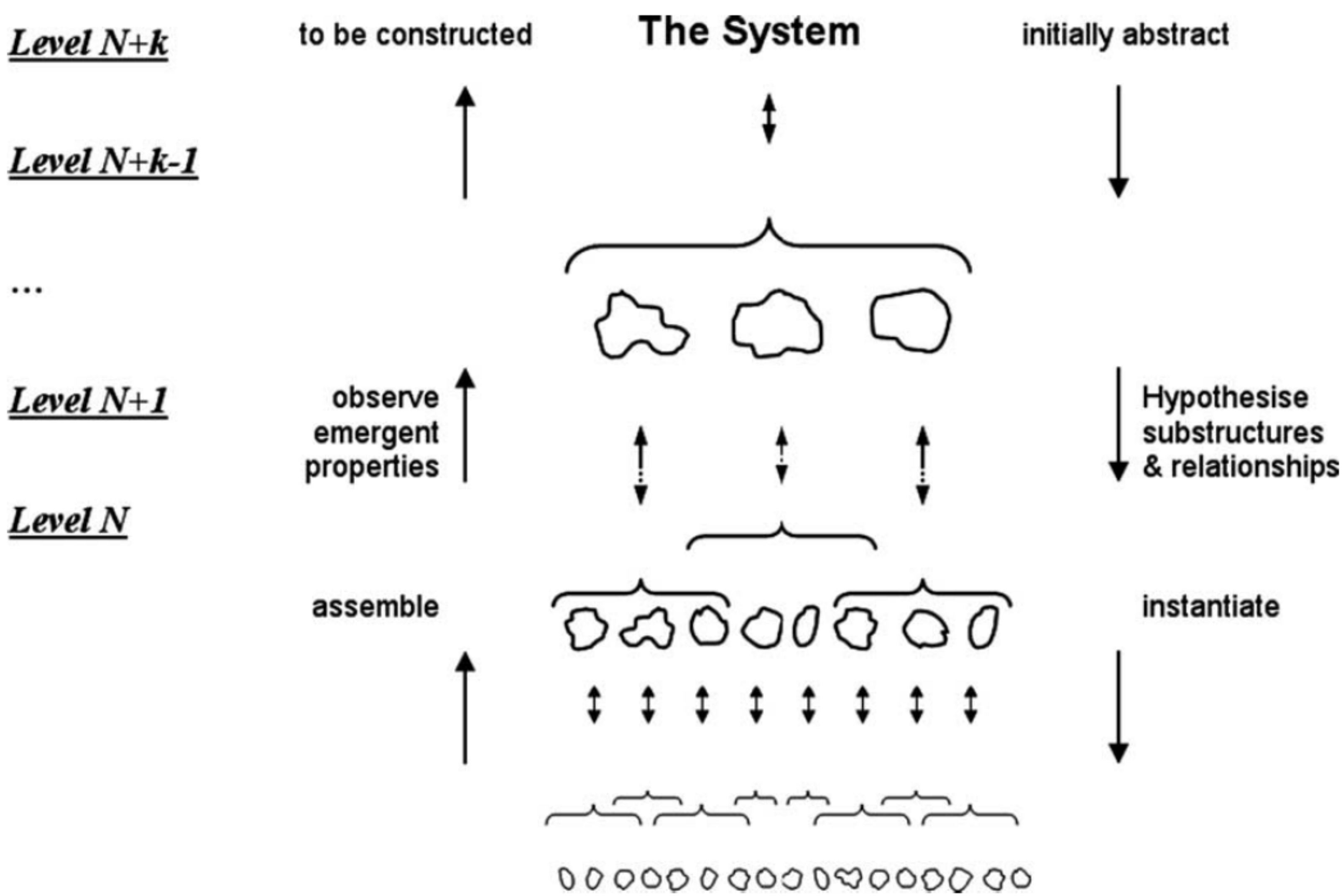
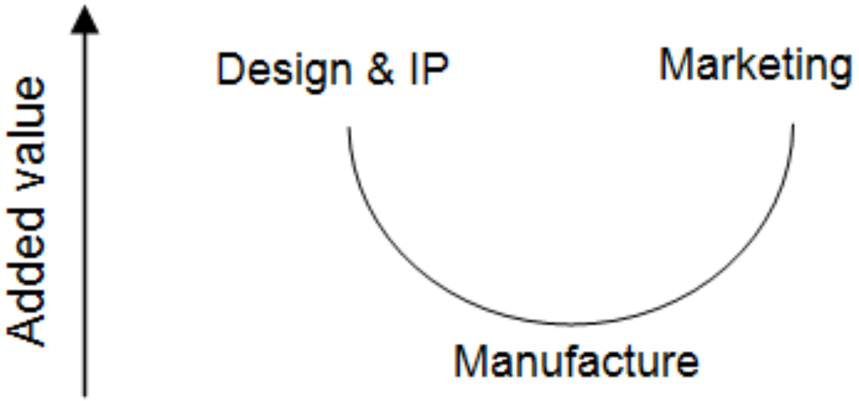


Fig 3. Design as bottom-up construction and top-down hypothesis, generation and reasoning.

Example: Innovation systems in China

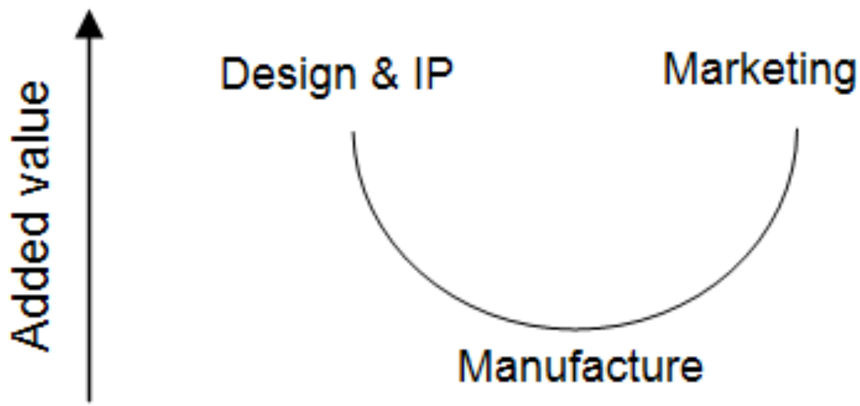


e.g. Apple
Designed in California
Manufactured in China
Sold worldwide

Manufacturing has lower value than design, IP and marketing

Policy: move to the ends of the smiles for greater added value

Example: Innovation systems in China



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Policy Question: what can the government do to improve innovation in China?

Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

necessary but *not sufficient* ingredients for successful industrial innovation:

Place	location with diverse resources and capabilities, e.g. cities
Education	school system to develop ability, Advanced Education
Elite	with spare time to think (researchers, rich people)
Passion	hunger to do something different & desire to make money
Money	Money to invest in R&D
Design	Design and IP, Marketing

Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

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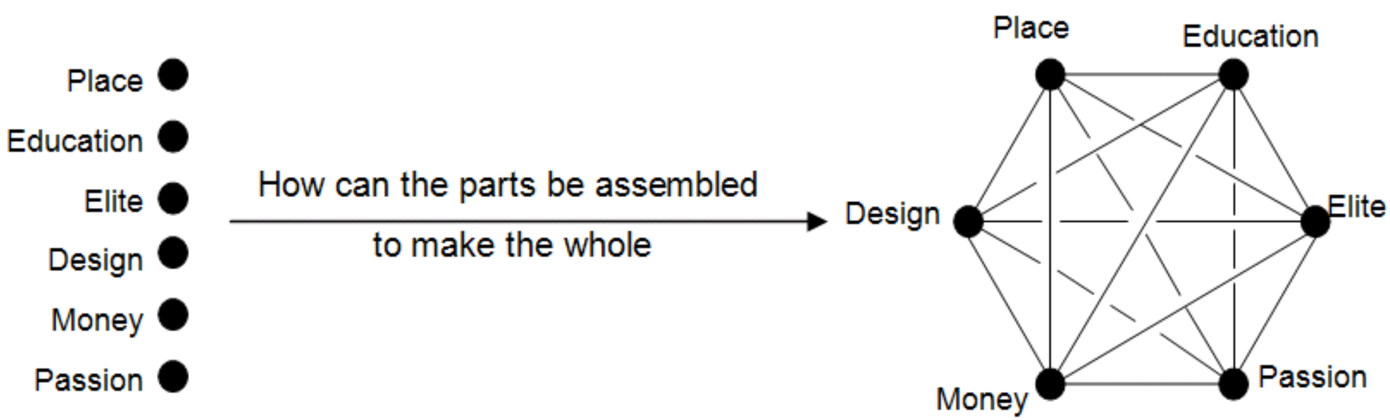
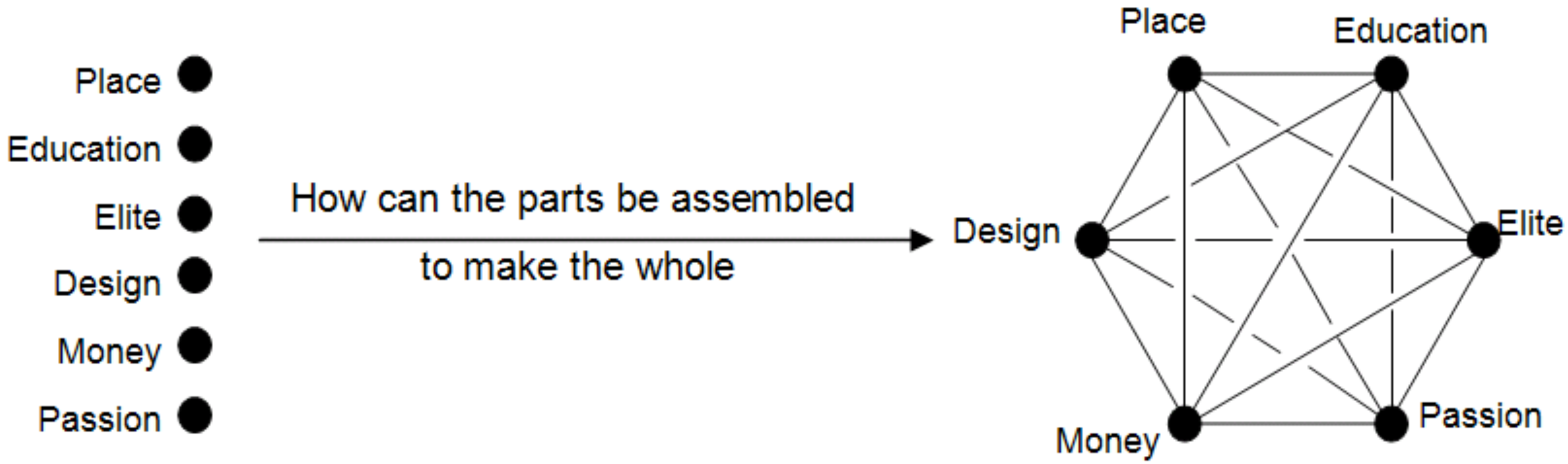


How can the vertices be assembled to form 5-dimensional hypersimplex

$\langle$place, education, elite, passion, money, design; $R_{innovation}\rangle$

Example: Innovation systems in China

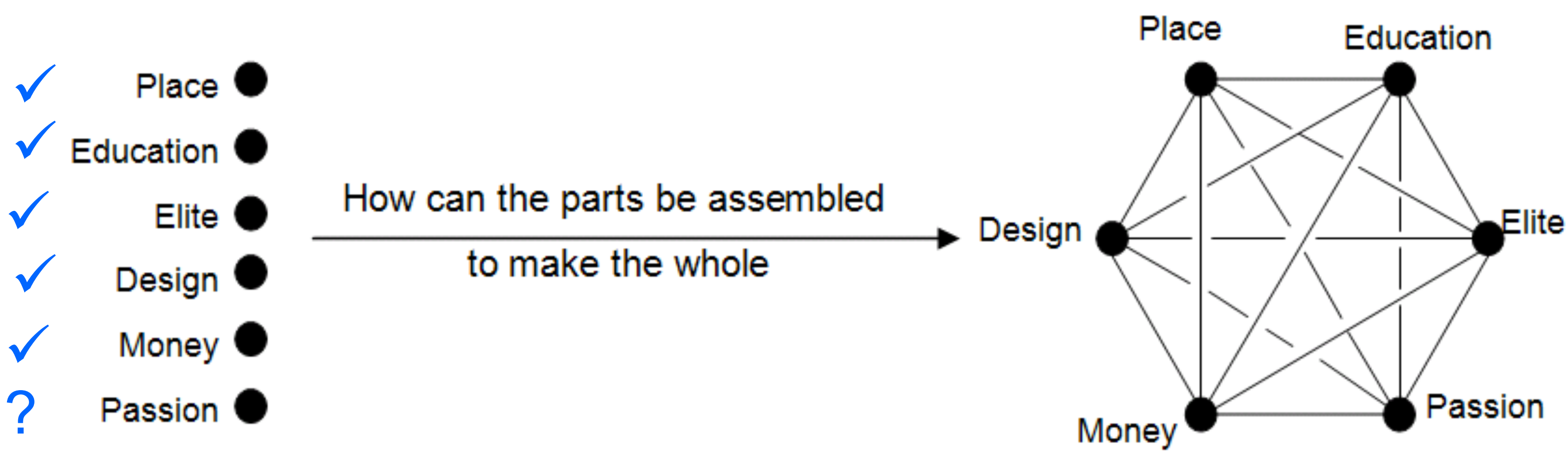
Policy Question: what can the government do to improve innovation in China?



Which vertices can the Government change?

Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?



Which vertices can the Government change?

Are any vertices missing?

If the Government changes the vertices will the simplex form?

Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

This is a multilevel system of systems

Place	World > China > Provinces > Cities > innovation clusters > …
Education	Universities > Teaching & Research x Types > …
Elite	academics, research fields – pure, applied > individuals > …
Passion	personality types, behaviours individuals
Money	tax breaks, grants, …
Design	specialisms, patents by type, …

Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

Scientific question: how can the Government know that policy might work?

predicting that an intervention kicks will result in a future target state

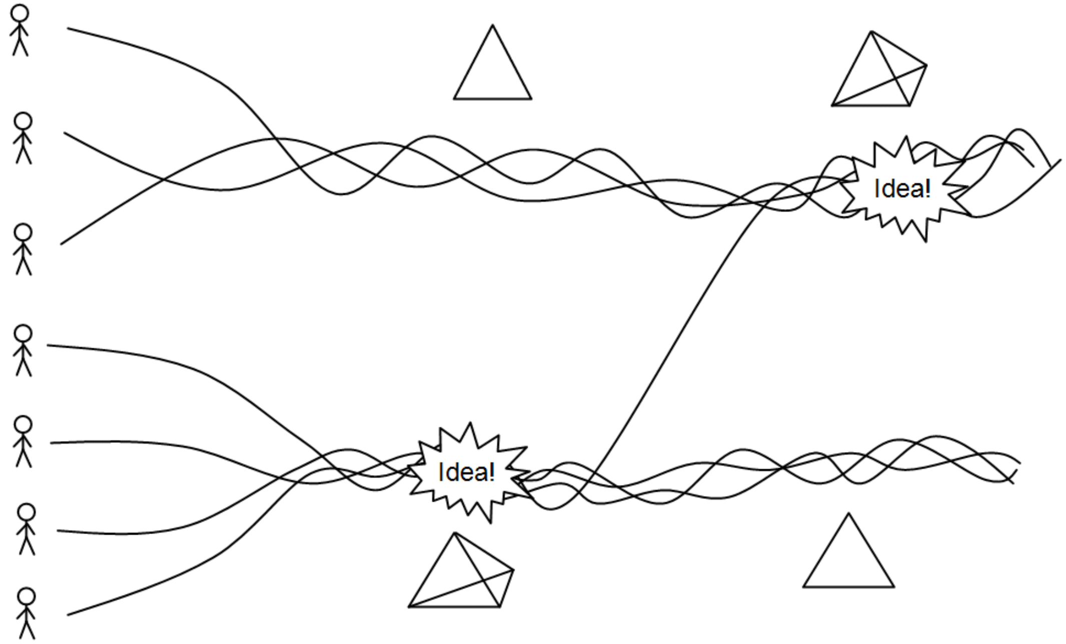
Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

Scientific question: how can the Government know that policy might work?

? Multilevel agent based simulations

e.g. micro-simulations at individual levels



Example: Innovation systems in China

Policy Question: what can the government do to improve innovation in China?

Detecting innovation in Big Data

Feature F_1 measured by number of new products sold

Feature F_2 trading patterns with other companies

Feature F_3 trading patterns with individuals

These patterns form relational simplices $\sigma_t = \langle F_1, F_2, F_3; R_t \rangle$

Then may have 'innovation hypersimplices' through time: $\langle \sigma_1, \sigma_2, \sigma_3, \sigma_4, \ldots ; R \rangle$

Example: Innovation systems in China

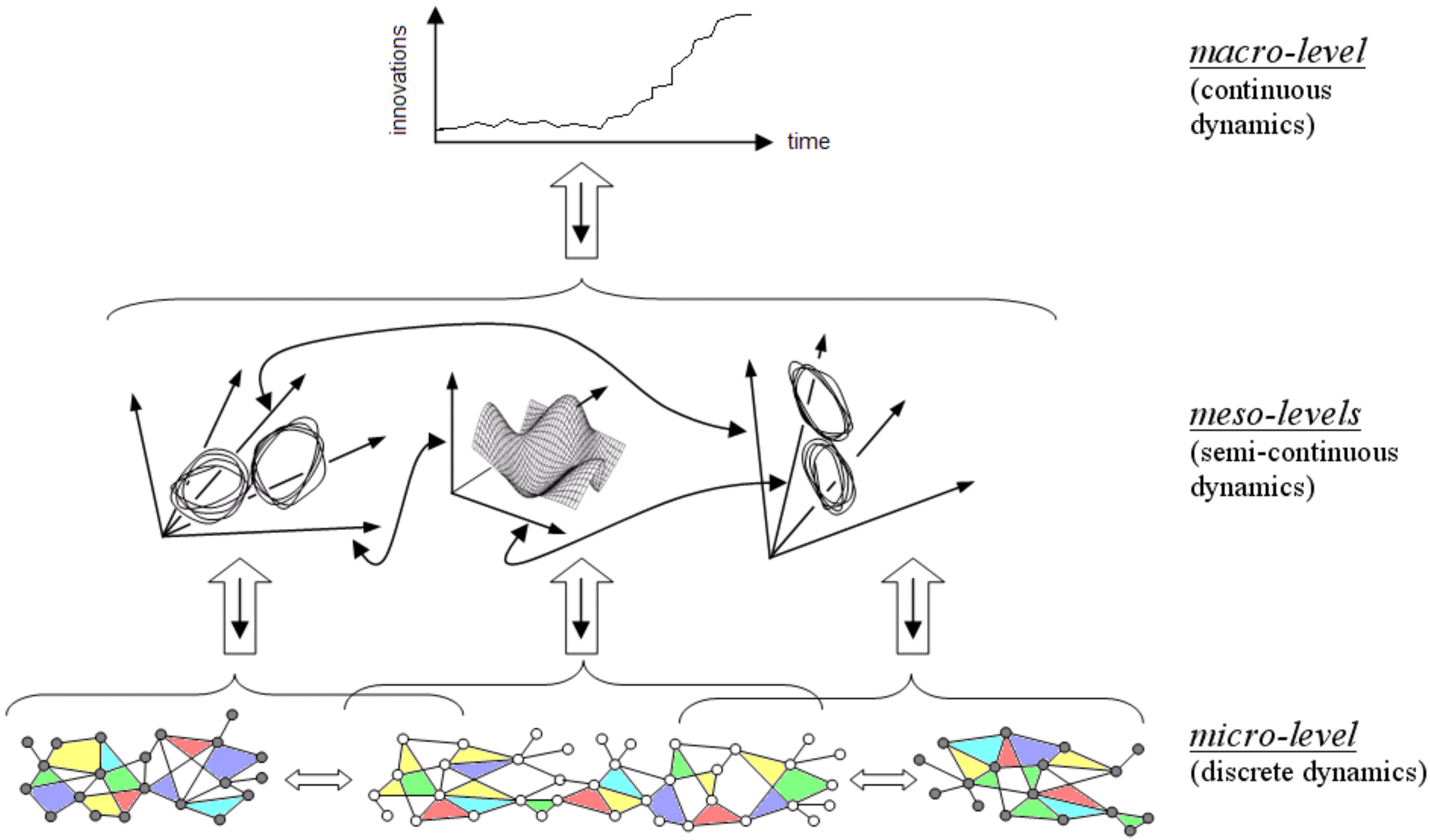


Figure 2. discrete micro-dynamic, semi-continuous meso-dynamics and continuous macro-dynamic

System dynamics as traffic on an evolving multilevel backcloth

Conclusions: Hyperneworks & Design in Global Systems Science

The 21st century coordination problem: Global Challenges spreading on global webs

Climate change impact, pandemics, financial instability, energy sufficiency, urbanisation ....

All these challenges spread on global webs and create interdependencies across these global webs: ‘systems of systems’. — Multilevel Hypernetworks

Coordination across global webs of different interests, cultures, economic interests .... becomes a main policy challenge: — Policy Design

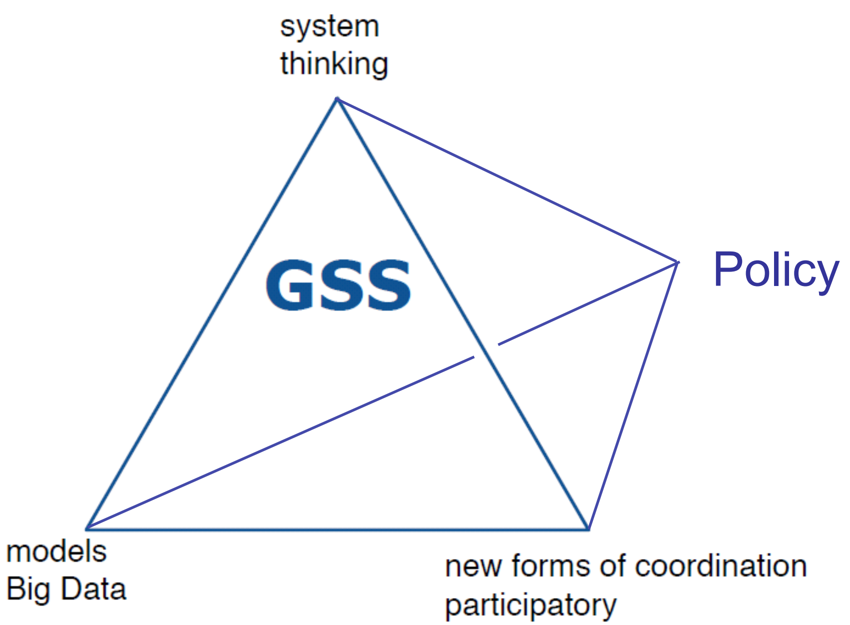
- Unintended consequences of actions
- Systemic risk (see financial crisis 2008)

In such ‘system of systems’, societies tends to address subsystems (countries, policy sectors....) and so fail to achieve systemic lasting change.

Policies need to be made coherent across webs of influence: Need for Systems approaches.

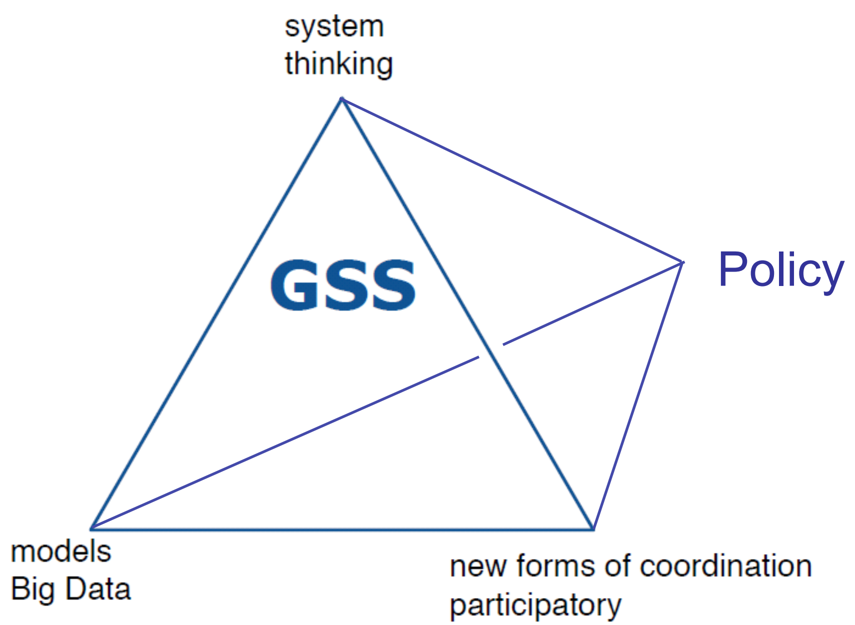
Ralph Dum:

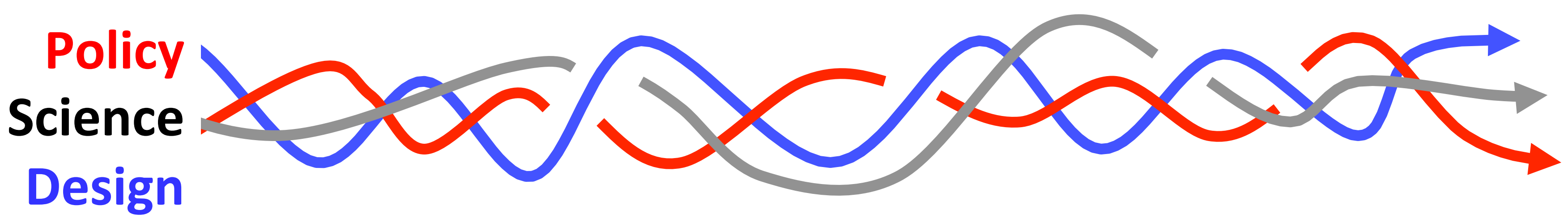
Conclusions: Hyperneworks & Design in Global Systems Science



Global Systems Science as a 3-simplex

Conclusions: Hyperneworks & Design in Global Systems Science





Conclusions: Hyperneworks & Design in Global Systems Science

- Hypernetworks augment standard network approaches to include relations between many things
- Hypernetworks give a natural way of representing multilevel structure and systems of systems of systems
- Design is the construction of new multilevel systems
- Policy is designing the future
- Science, policy and design are inextricably entangled
- GSS, policy, design & hypernetworks are inextricably entangled