

Physical Complexity



Part A: Emergent behaviour
in physical infrastructures

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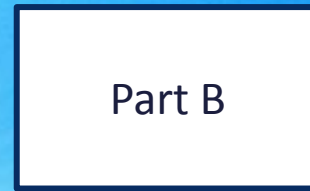
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Emergent behaviour

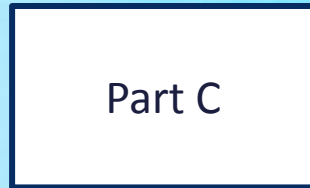
- Behaviour at the macro-level emerges from the behaviour of system elements at the micro-level.
- Often unpredictable



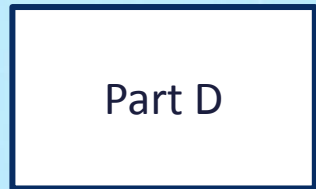
Behaviour =
predictable



Behaviour =
predictable



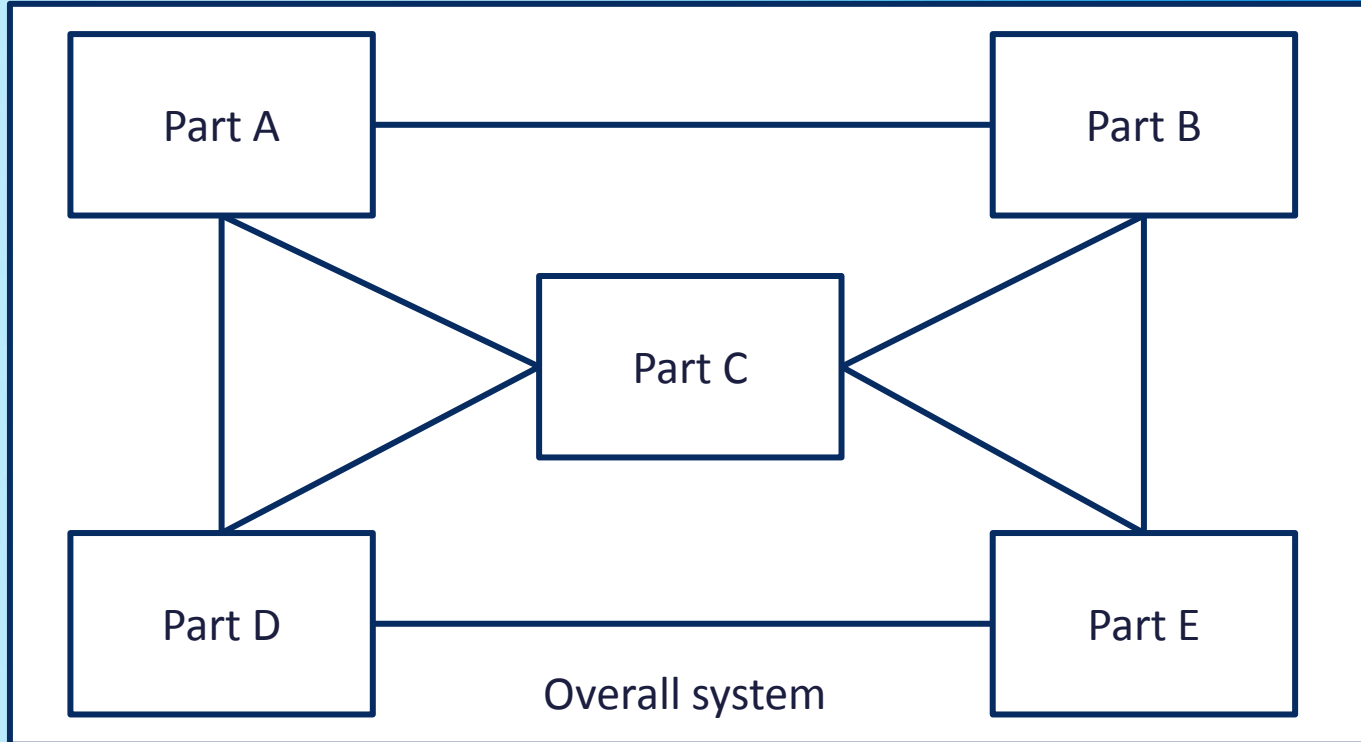
Behaviour =
predictable



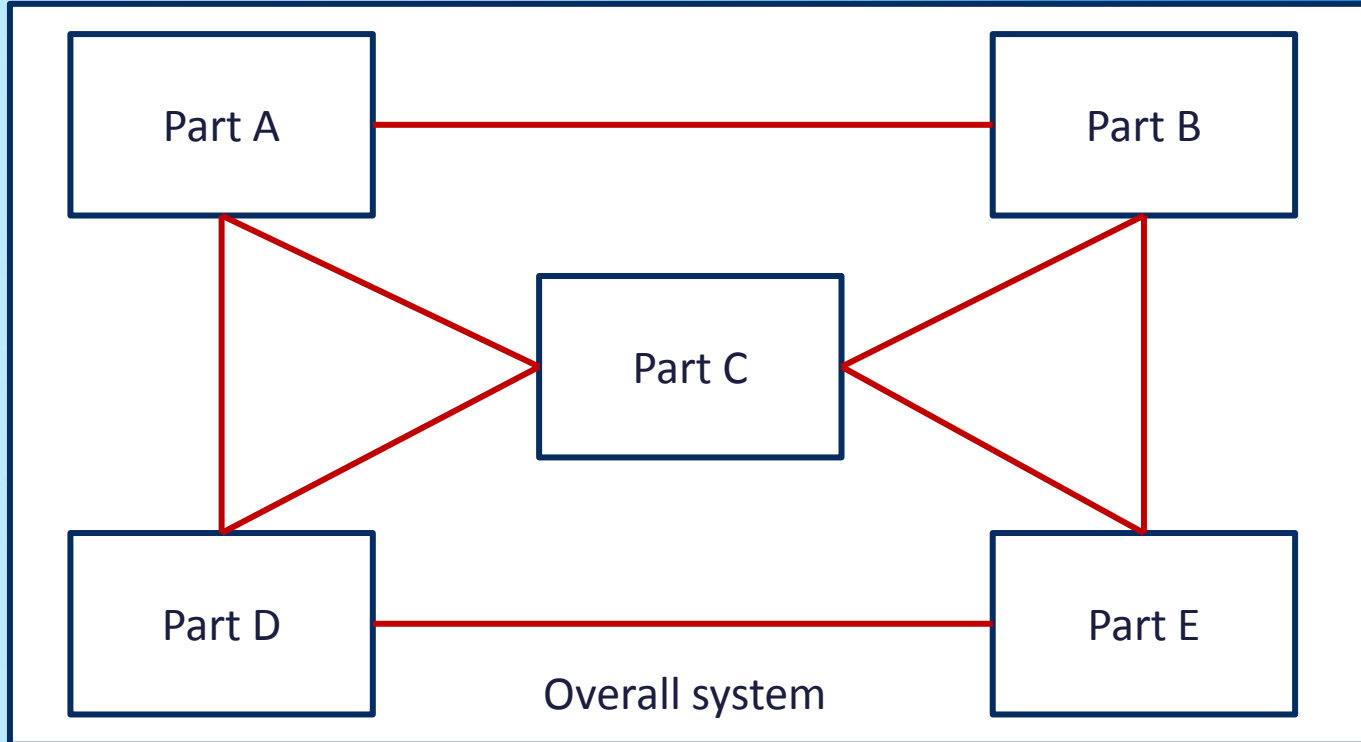
Behaviour =
predictable



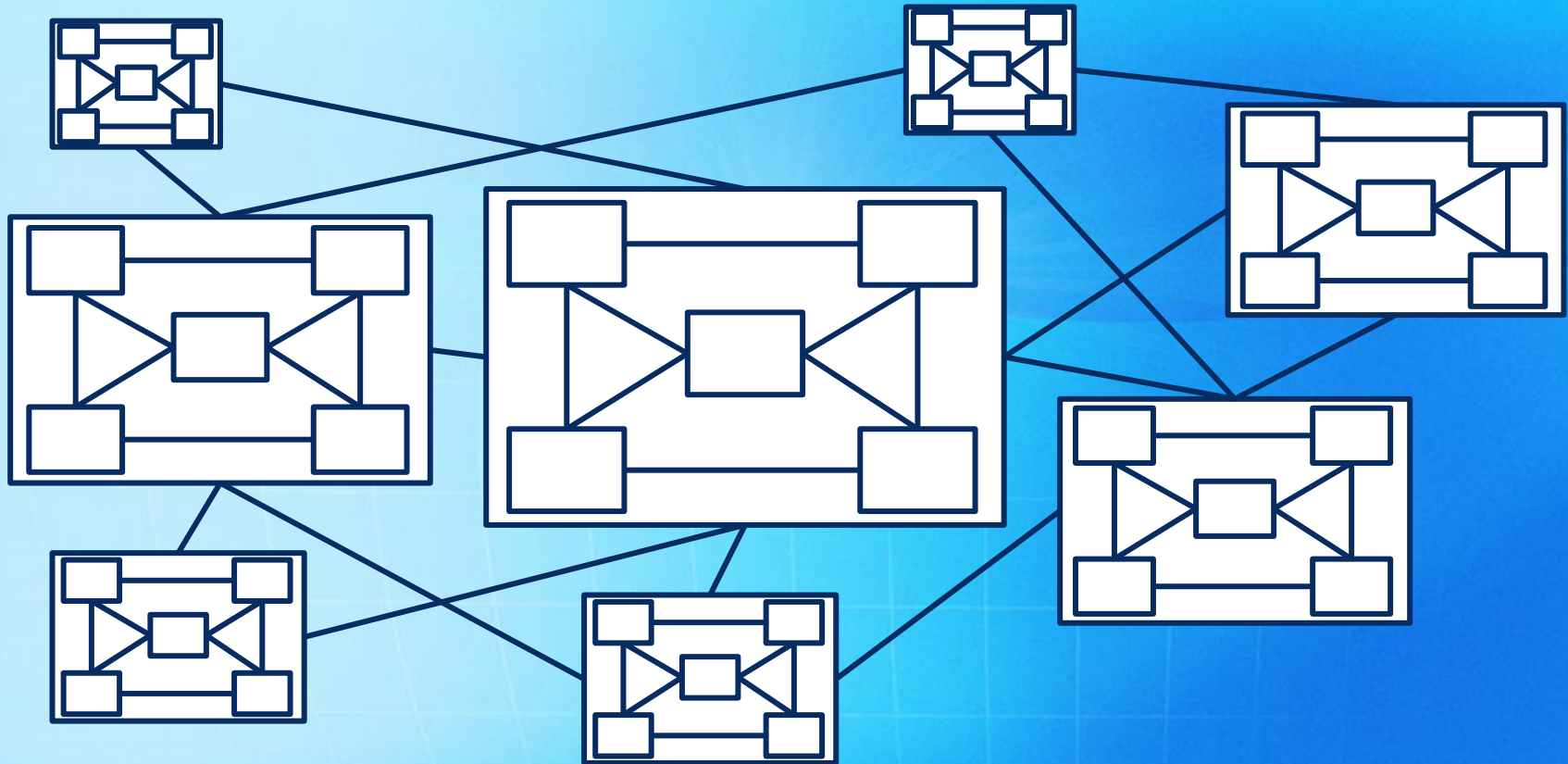
Behaviour =
predictable



Behaviour can be **unpredictable!**



Complexity is in the **interactions**



Emergence is everywhere



Emergence is everywhere



Emergence is everywhere



Emergence is everywhere



Emergence is everywhere

Economy

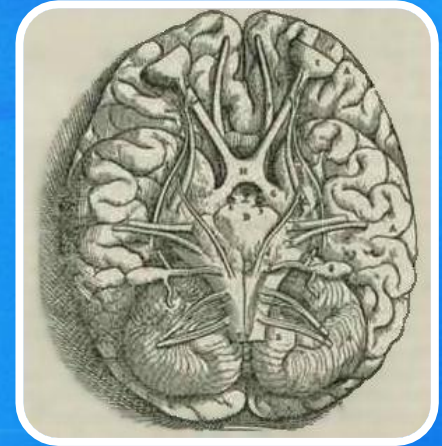
Psychology

Biology

Dow Jones Industrial Average

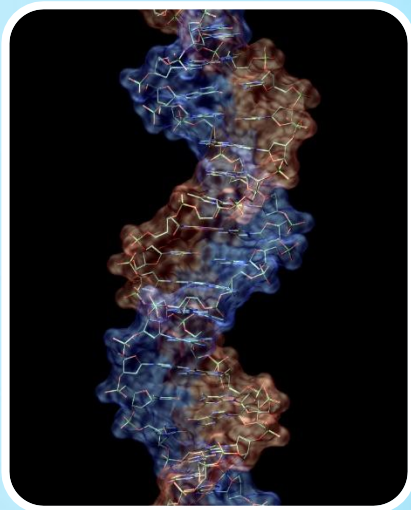
(Dow Jones Global Indexes:INDU)

16,277.85 ↓ -24.92 / -0.15% 14,395 16,588 -1.75%
Real-Time Quote Today's Change 52-Week Range Year-to-Date

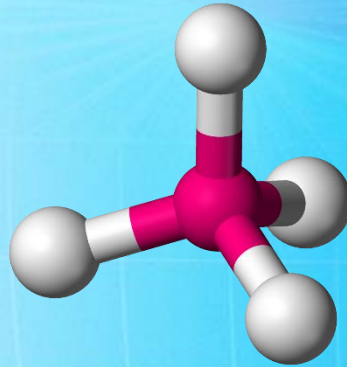


Emergence is everywhere

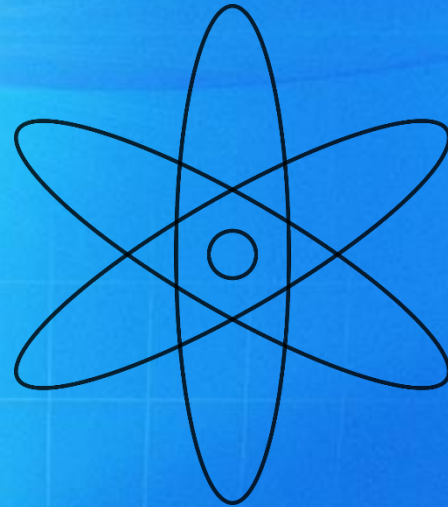
Biology



Chemistry



Particle physics



Emergence is everywhere



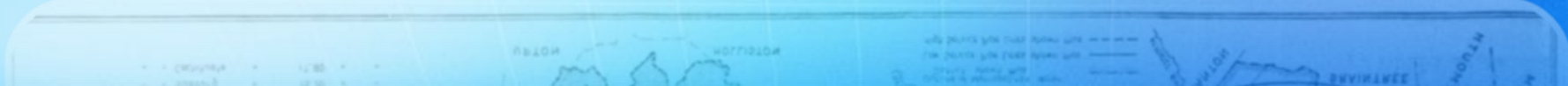
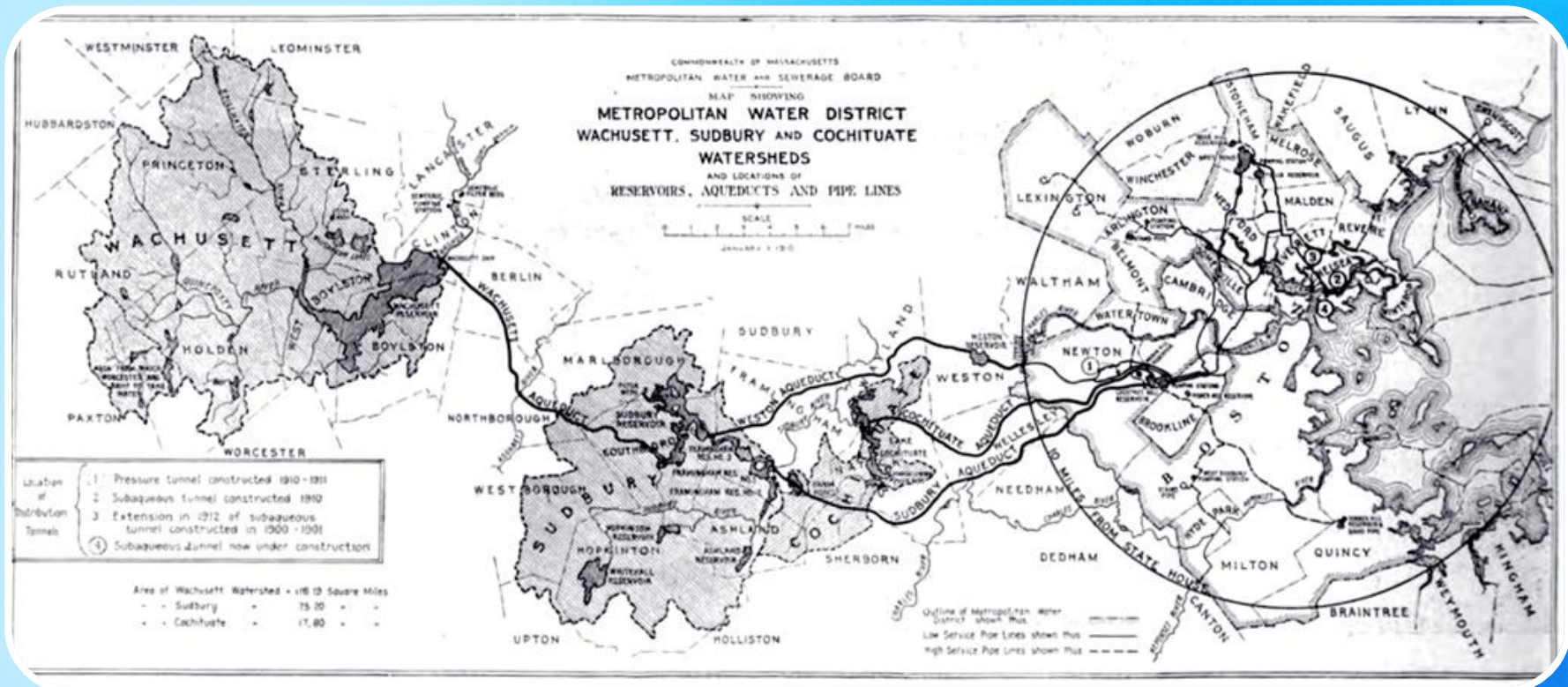
Legacy Infrastructures

- Are a patchwork of local, regional and national networks
- Were subject to national standards



Legacy infrastructures

- Are a patchwork of old and new technologies





Ageing infrastructures

- Yorkshire water: 40 % loss due to leaking pipelines, 1990's
- Asset life cycle management standards



Changing functionality

- Cross-border interconnectors
- From back-up facility to accommodating international electricity trading

Changing functionality

- The nature of electric power generation is changing
- More and more electricity generated from renewable sources

Germany

- Wind parks in the northern part
- Load centers in the southern part
- A lack of interconnection capacity between the northern and the southern part
- Electricity flows via neighbouring countries



Flow pattern is changing

- More wind power
- More solar power
- Higher risk of instability



Electricity infrastructures

- Little storage capacity
- Hydropower reservoirs



Electricity infrastructures

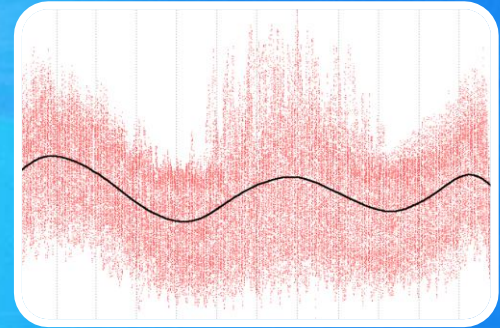
- Little storage capacity
- Hydropower reservoirs



Electricity infrastructures

- High velocity of electricity flows
- Balancing of supply and demand in real time

Balancing supply and demand



Supply

Demand

Balancing supply and demand



More challenging!

Thank you for your attention!

Please post any questions you may have on our discussion forum.

Physical Complexity



Part B: Drivers of infrastructure development

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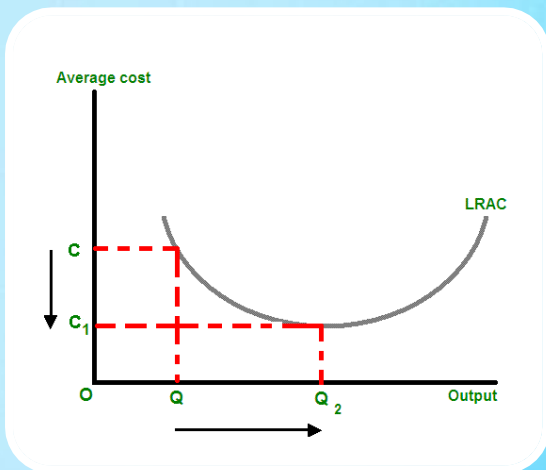
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Predictability

- **Small system:** possible to predict
- Tendency to grow because of:
 - Economies of scale
 - Network externalities
- **Large system:** almost impossible to predict behaviour

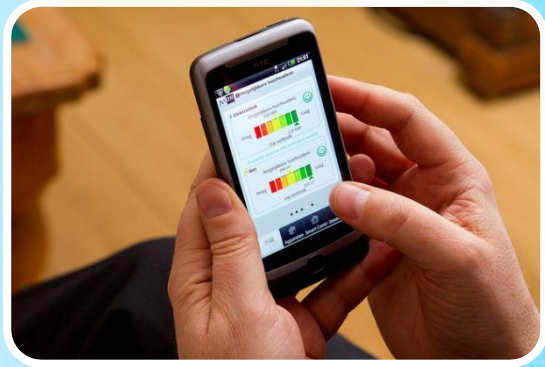
Economies of scale

- Decreasing cost per unit of output with increasing scale



Network externalities

- The more users, the more value for each user



Interdependencies

- Infrastructures have a tendency to grow into huge systems
- Subsystem failure may cause overall system failure
- Interdependencies can have various forms, e.g.:
 - Linear
 - Non-synchronous

Interdependencies

- More subsystems
- More (diverse) interrelationships
- More feedback loops
- Difficult to recognize and model

Patterns of emergent behaviour

- Patterns in aggregated behaviour of infra-systems
- Recognizing patterns is crucial for operators
- Operators use models to predict the implications of their actions

Path dependency

- Infrastructures: capital intensive



Huge **sunk costs**
(costs that cannot be recovered)

Sunk costs in networks

- Netherlands: 37,350 km²
- Hundreds of thousands km of cables and pipelines
- Almost 10,000 km of overhead lines
- High sunk costs → path dependency



New technologies

- Can be adopted if competitive
- For example: Mobile telephony:
 - Relatively small network investments
 - Flexibility
 - New services

Mobile telephony in emerging countries



Connect with MTN and get Mphahle benefits.

HOUSE OF TECHNICIANS
FRIDGE REPAIRS

:083339...

COMPUTER SERVICES

066666629755



PHONE REPAIR



:0737510108

SHAFIQ NISSEY SALE

Concept of agents

- Interacting elements
- Agent = decision making entity



Rules

...

...

...

Definition of infrastructure

- Not only physical network
- An infrastructure includes:
 - *Transport and distribution network*
 - *Carriers*
 - *Conversion and storage facilities*
 - *Governance, management and control systems*
- Actors are part of system →
Social complexity

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References

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