A UNIFIED FRAMEWORK FOR COLLECTIVE SYSTEMS

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Grand Vision

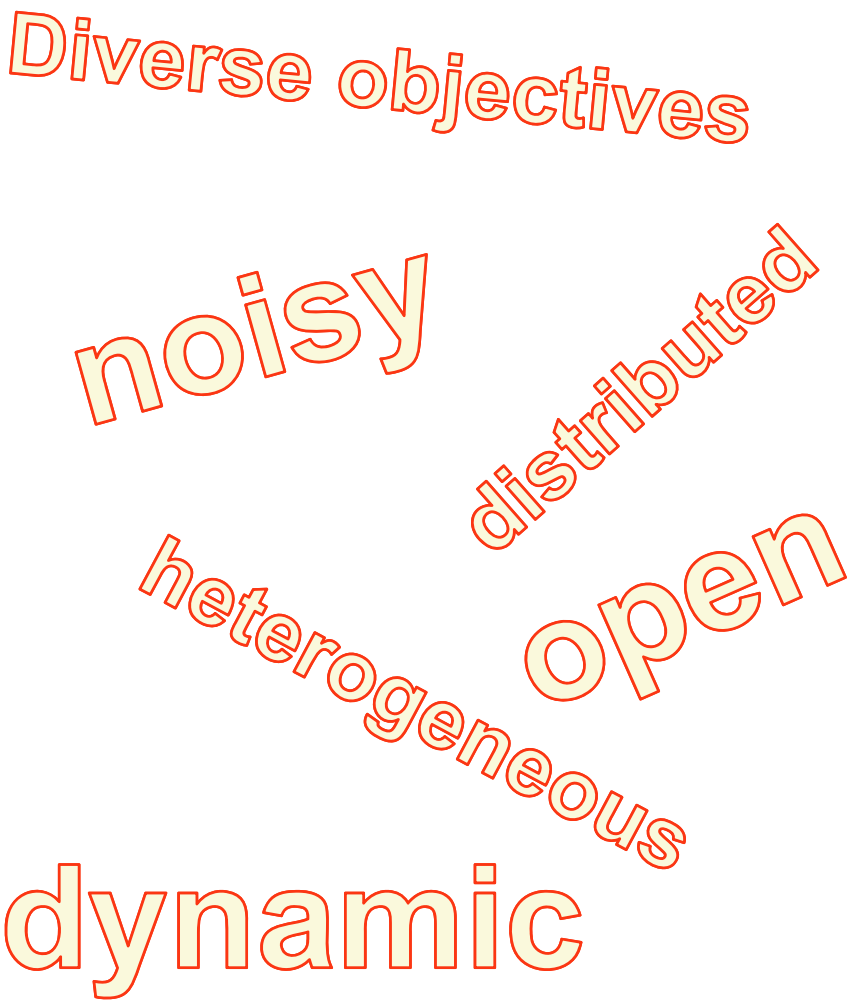
Applications

A Software Toolkit of Design Patterns and Components

A Unified Theory of Operations for CAST Systems

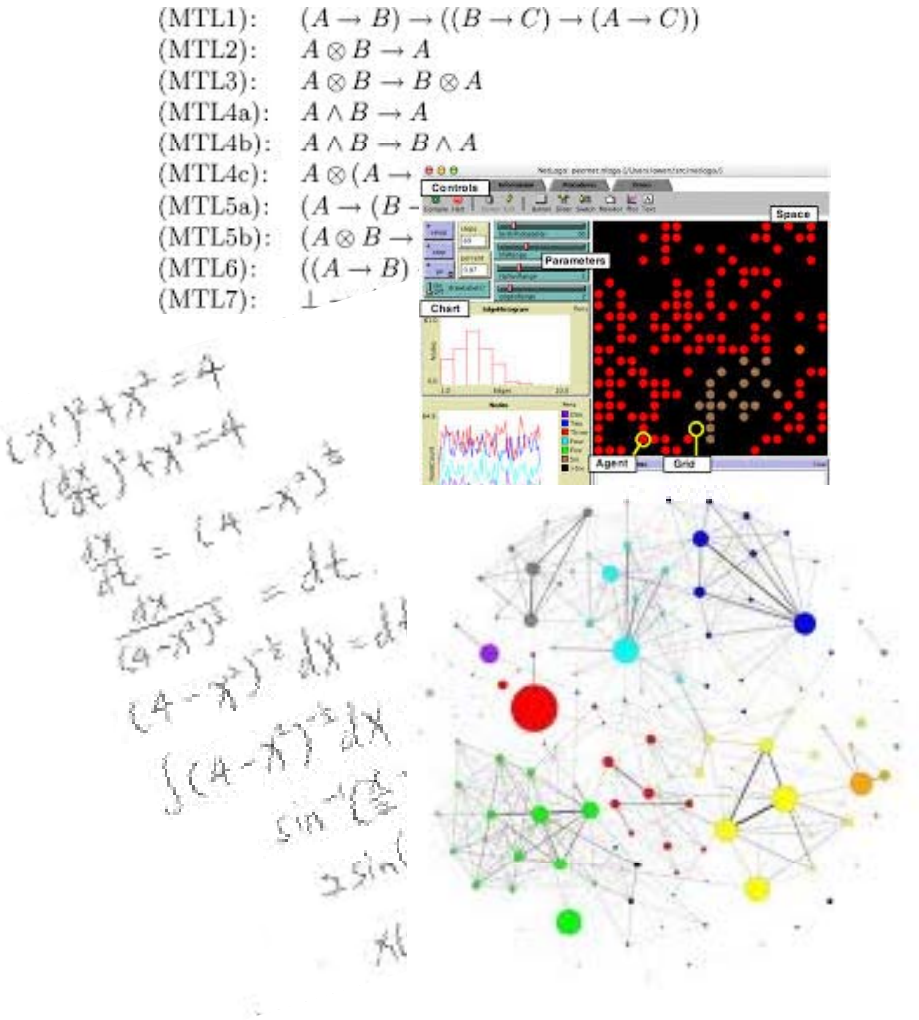
Why do we need a new theory ?

- Existing engineering approaches provide some theoretical basis
  - E.g. control theory – ensure/prove stability
- But most methods don't account for defining properties of CAST systems
  - Lead to systems that are oscillatory or at worst unfit for purpose
- Existing methods often domain-driven (e.g. telecoms, robotics)
  - Not generalisable or transferable



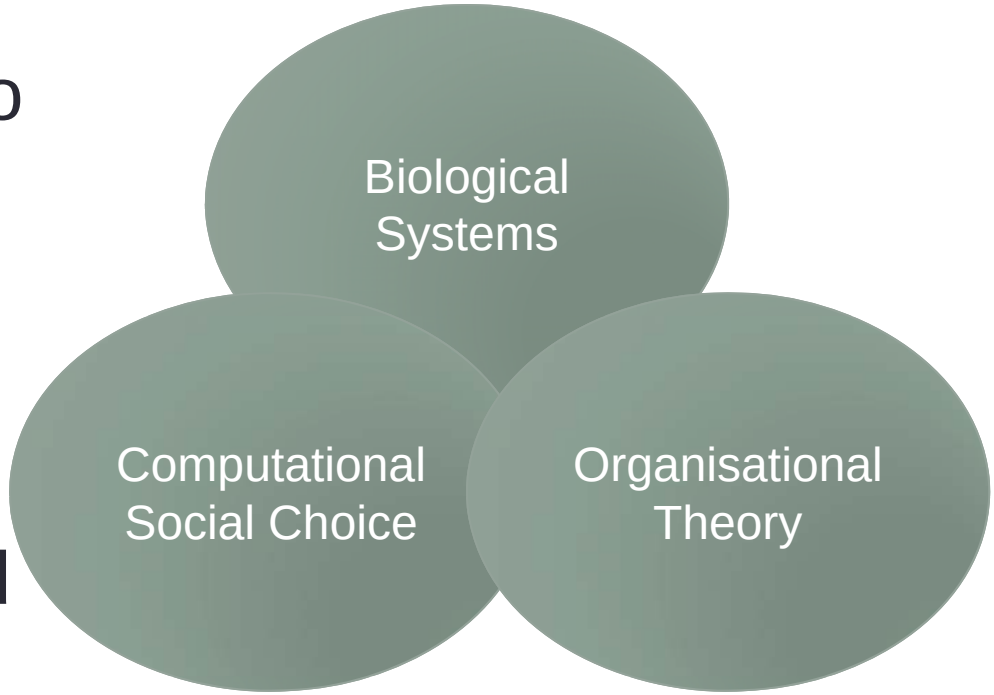
CAS is Multi-Disciplinary

- Many theories from individual disciplines
- Hard to compare theories
- Theories address different aspects of CAS
- Don’t account for engineering constraints



Towards a unified theory

- Unifies concepts from multiple disciplines into a single framework
- Qualitative theory represented in axiomatic form
- Can be formalised and analysed
- Operationalised via design patterns



Biological Systems

- Immune-neuro-endocrine mechanisms lead to *homeostasis*
- Cohen's cognitive immune system :
  - Decision making via co-respondence
- Swarm insects
  - Coordination, partial info
- Symbiosis between multiple species:
  - Cooperation

- *Long-term stability*
- *Adapt over multiple timescales*
- *Coordinate multiple heterogeneous components*
- *Deal with limited and partial information*
- *Decision making*
- *Conflict resolution*

Social Choice Theory

- Originates in *economics* and *political science*
- Concerns design & analysis of methods for aggregating preferences of multiple agents into collective decisions
- Social choice considers formal aspects of democratic decision making (e.g electoral systems)
- *Computational* Social Choice add an algorithmic perspective

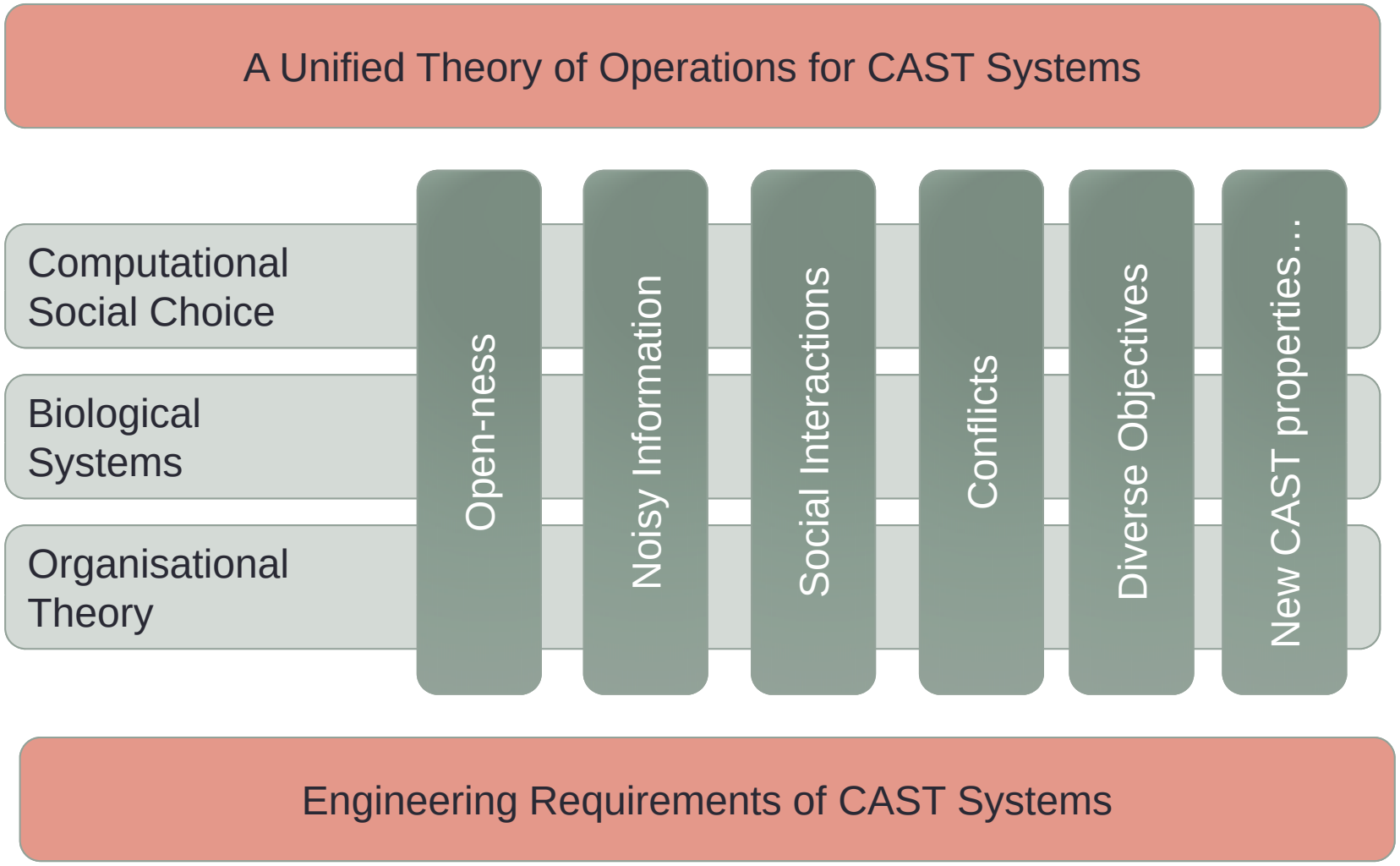
- Heterogeneous agents
- Multiple objectives
- Collective decisions
- Open-ness
- Fair division of resources
- Stability

Organisational Theory

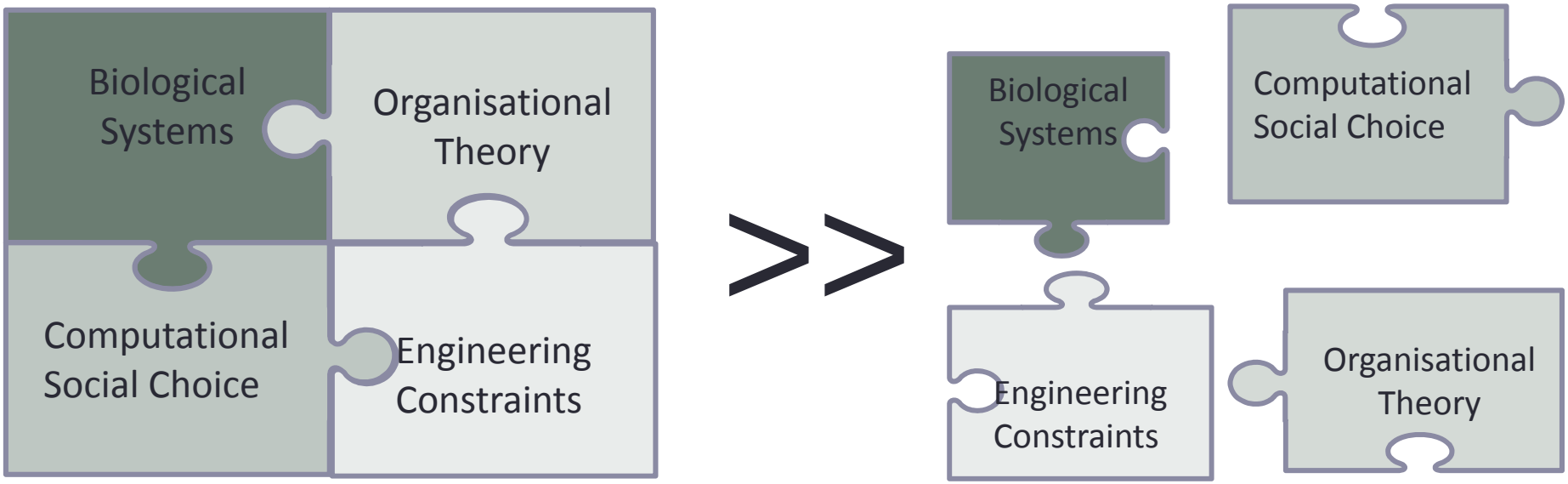
- Elucidates principles for stable resource management
- Study of engineered systems
- Insights into engineering socio-technical ‘organisations’ in a top down manner

- Collective Action
- Trust
- Cooperation
- Stable and enduring systems

A Unified Theory of Operation



What does synthesis give ?



- Addresses weaknesses in individual theories
- Addresses conflicts
- Respects engineering constraints

Individual Weaknesses

- **Biological Systems**:
  - Tend to rely on homogeneous collectives
  - Global rather than individual objectives
  - Considerable physical differences
- **Computational Social Choice**
  - Based on standard models from economics
  - Abstracted from human decision making (different goals but same model)
- **Institutional Theories**
  - Easy to get locked into sub-optimal states due to path dependencies
  - Not clear how to evaluate ‘fitness’ of an institution

Conclusions

- Unification addresses current fragmented approach to inter-disciplinary research
- Different analysis tools currently hinder elucidating connections between fields
- Many existing theories don’t account for engineering constraints of CAS
- A unified theory will:
  - Enable formal comparison between concepts from different disciplines
  - Drive innovation in field