SHOAL

A Systems Approach to Design For Resilience

Climate Smart Engineering 2023

Outline

- Critical infrastructure is exposed to systemic risk
- Design for resilience requires an understanding of the adaptive capacity of the system
- Systems Engineering is a discipline used to understand and decompose complexity in system design
- Introduce a conceptual framework to
  - Identify points of leverage to increase resilience community resilience
  - Provide rigorous capability design early in the life cycle of critical infrastructure projects to ensure current and future needs are met

Why?

If [resilience is] integrated early in design, spending just an additional 1% of new infrastructure project budget can provide effective mitigation to natural hazards and climate change. [**1**]

[1] The International Bank for Reconstruction and Development, 2010. *The Cost of Adapting to Climate Change for Infrastructure*

Setting the Context

“There are places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything.”

Donella Meadows, 1999

The Challenge

- We are dependent on interconnected critical infrastructure to service our communities
- The effects of systemic risk is difficult to predict because it cascades through these interconnected systems
- To secure ongoing resilience and prosperity we need to
  - understand the causes and effects leading to risks, and
  - how these intersect vulnerability in society

Current *solutions* may not address future novel, unprecedented, emergent, and changing risk

Solutions can only be identified or developed through an inclusive process, taking a **system wide approach** and considering the **contextual factors driving risks**

Critical Infrastructure

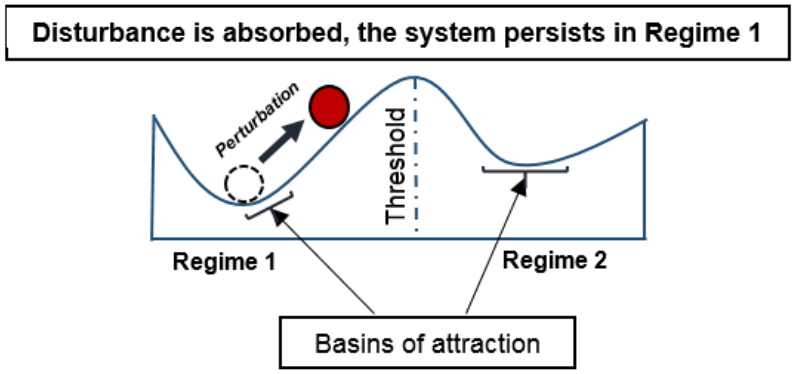
- Physical facilities, supply chains, systems, assets, information technologies, and communication networks
- Significant impact to social or economic wellbeing if compromised or rendered unavailable

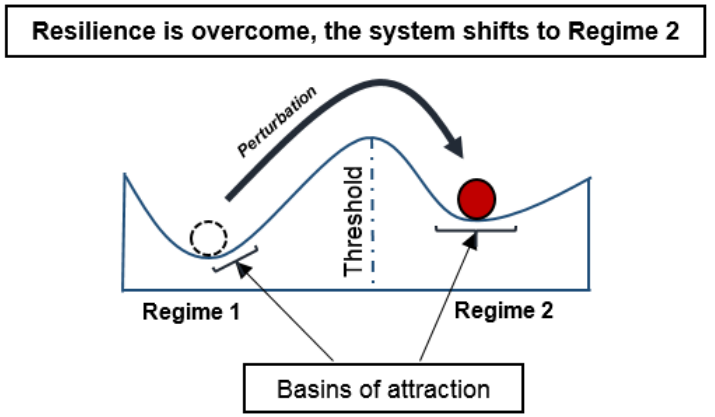
Resilience

- Withstand shock events to continue operating
- Return to service as soon as possible after any disruption
- Responds to long-term stresses

Systems View of Resilience

- Absorb disturbances to retain the same function and structure
- Concerns the adaptive capacity of an entire system, not just its constituent parts
- The interrelationships between the system and disruptions must be understood



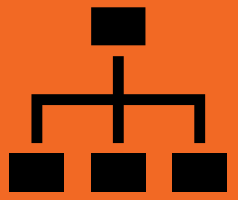


Resilience

- Withstand shock events to continue operating
- Return to service as soon as possible after any disruption
- Responds to long-term stresses

A focus on physical infrastructure alone will not achieve this

Infrastructure

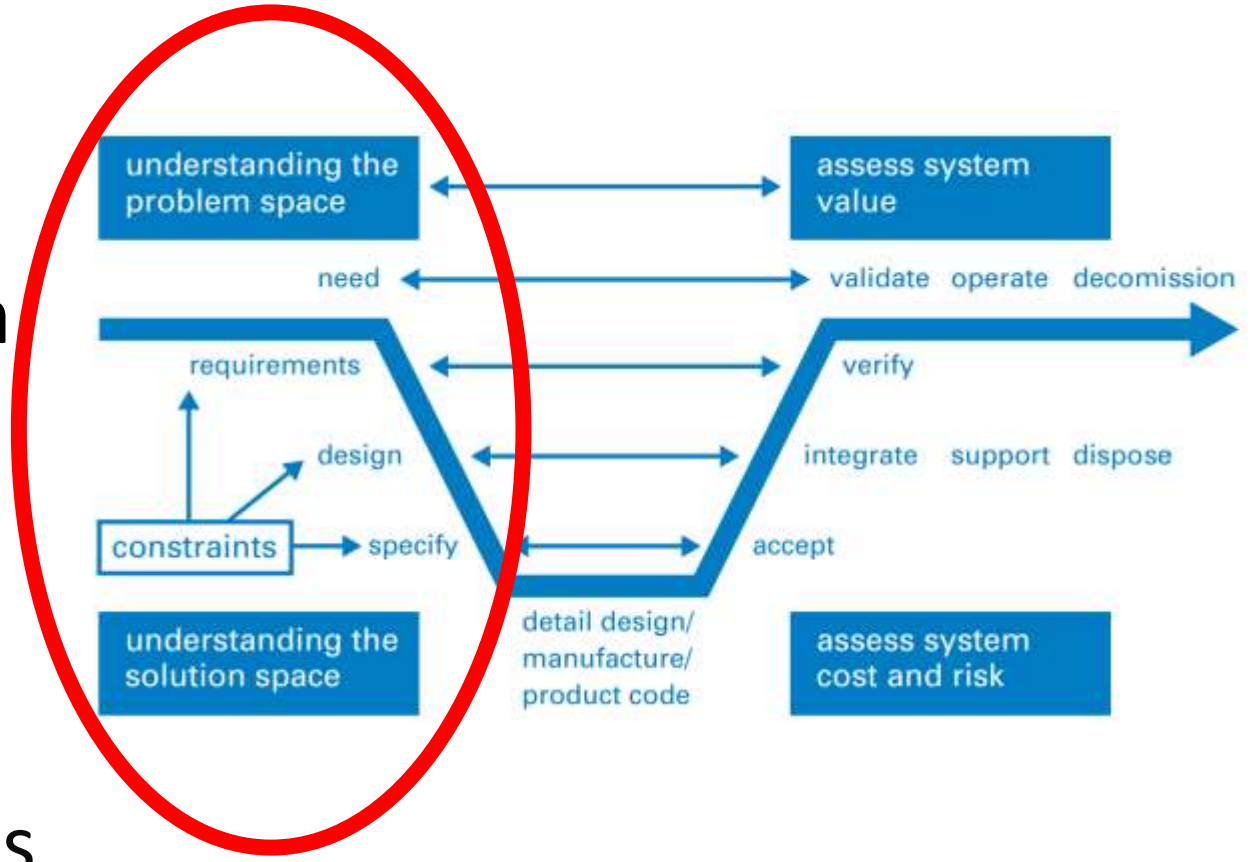


Organisational

Community

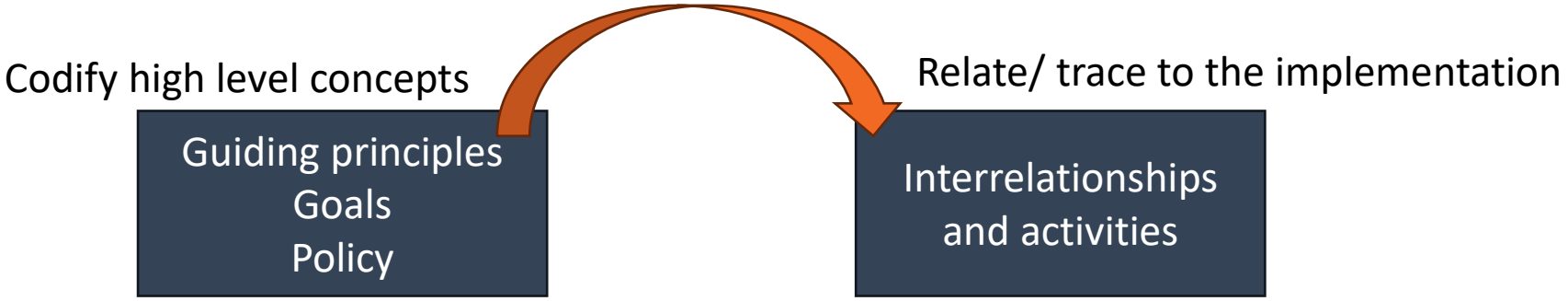
Systems Engineering

- Systems Engineers work with stakeholders, design engineers, SMEs, and managers to decompose complexity in system design
- Facilitate the exploration of options and capture decisions, with rationale
- Integrate information from across multi-disciplinary domains



Model Based Systems Engineering

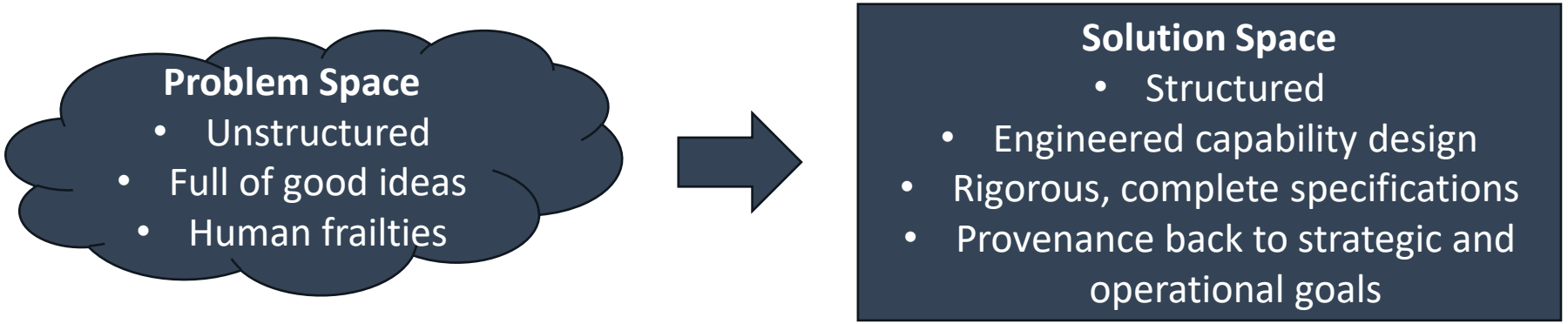
- **Information-centric approach** rather than a document-based approach



- Having a picture, a model, of this inter-connectedness is valuable

Aims

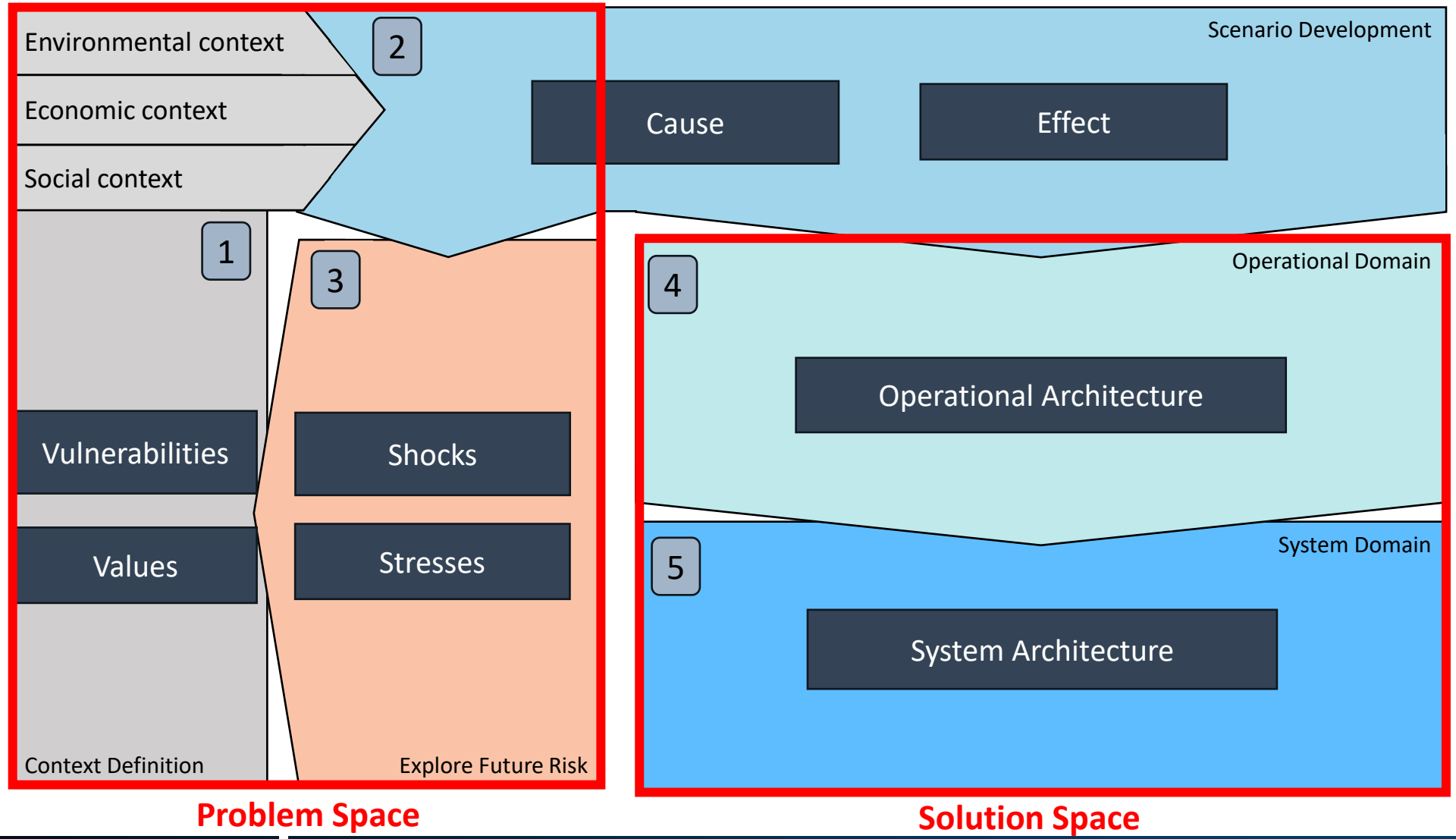
- Bring together Resilience and MBSE concepts to:
  - Identify points of leverage to increase community resilience
  - Provide rigorous capability design early in the project life cycle
  - Understand the contribution the project makes to the resilience of the broader network, place, or community



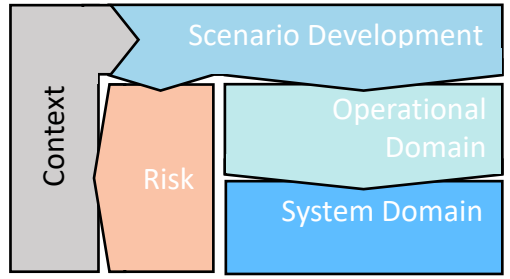
Design for Resilience

A Conceptual Framework

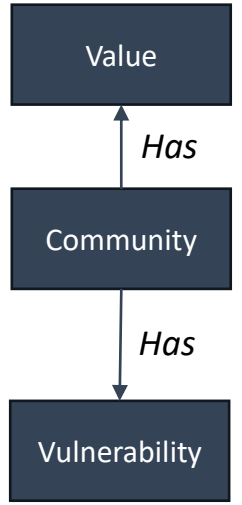
Framework for Resilience



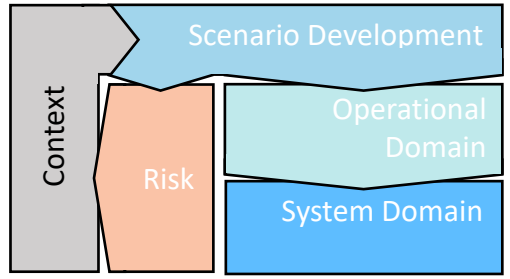
Context Definition - what



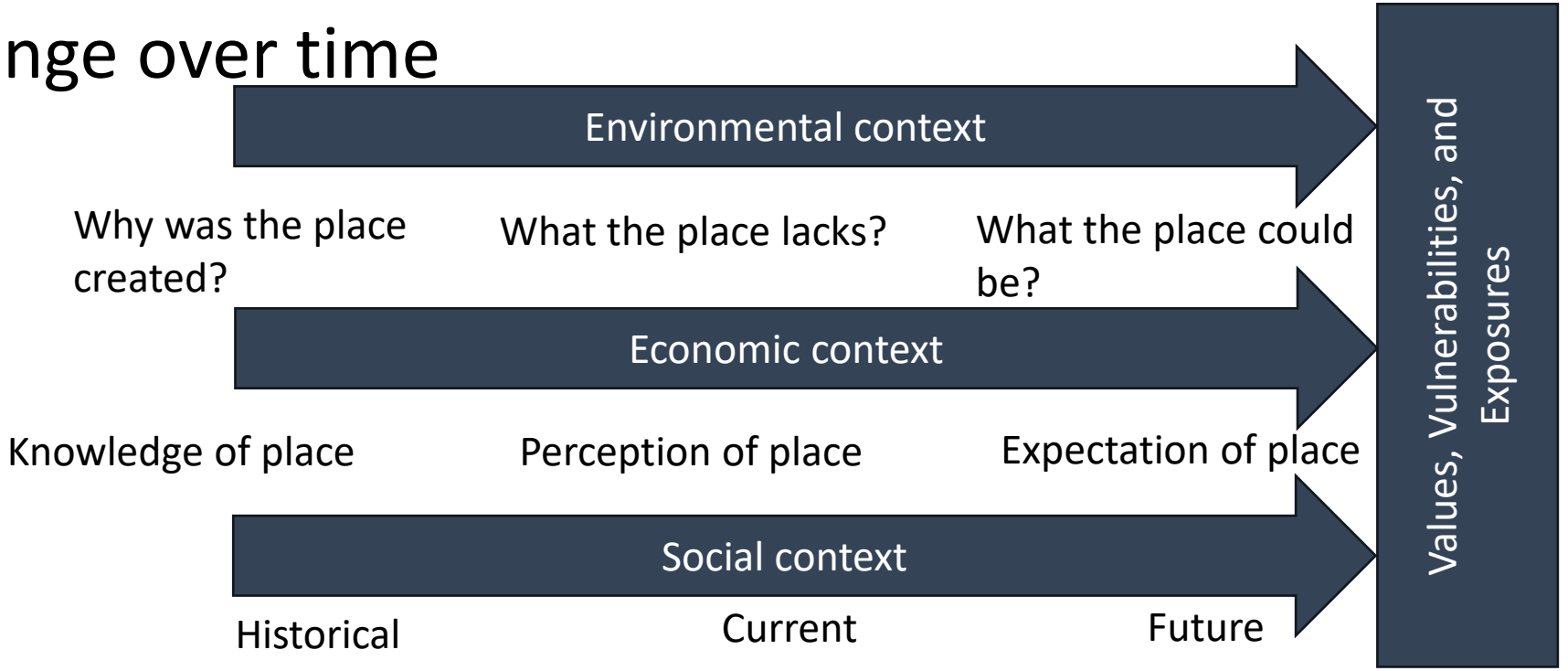
- Design for resilience is highly contextual
  - Resilience **of what** and **to what**?
- Elicit community vulnerabilities and values
  - Values in tension (what people desire in times of stability vs times of disaster)



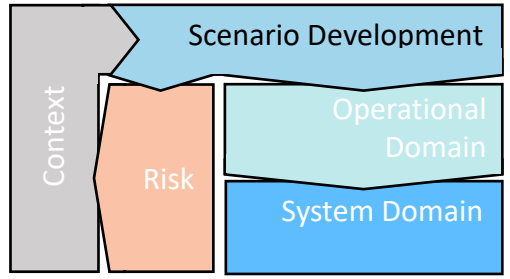
Context Definition - how



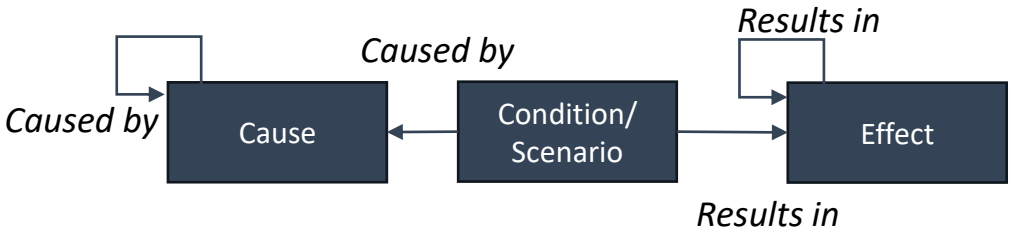
- Engage with the community/ place
- Environmental conditions, societal perspectives influence and are influenced by future risk
  - Change over time



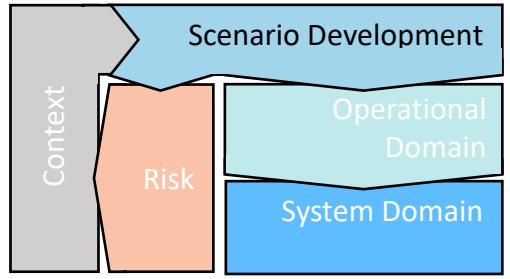
Scenario Development - what



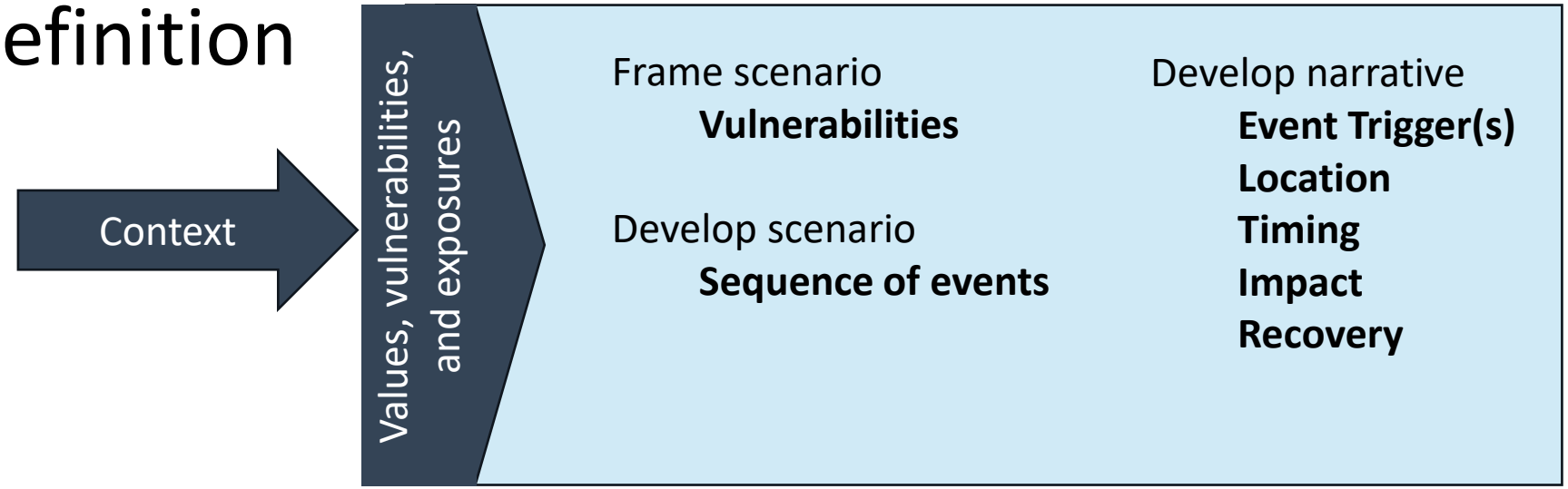
- A tool to cope with uncertainty
  - Support creative thinking about plausible futures
  - Not a prediction of future disruptive events or disasters
- Capture causal relationships and driving forces
  - Cause and effect (if, then?)



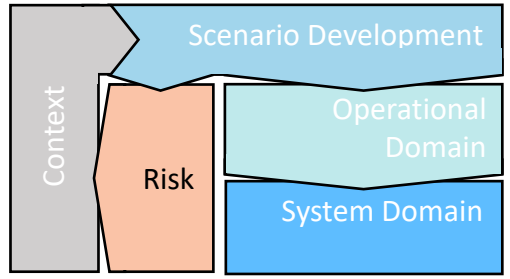
Scenario Development - how



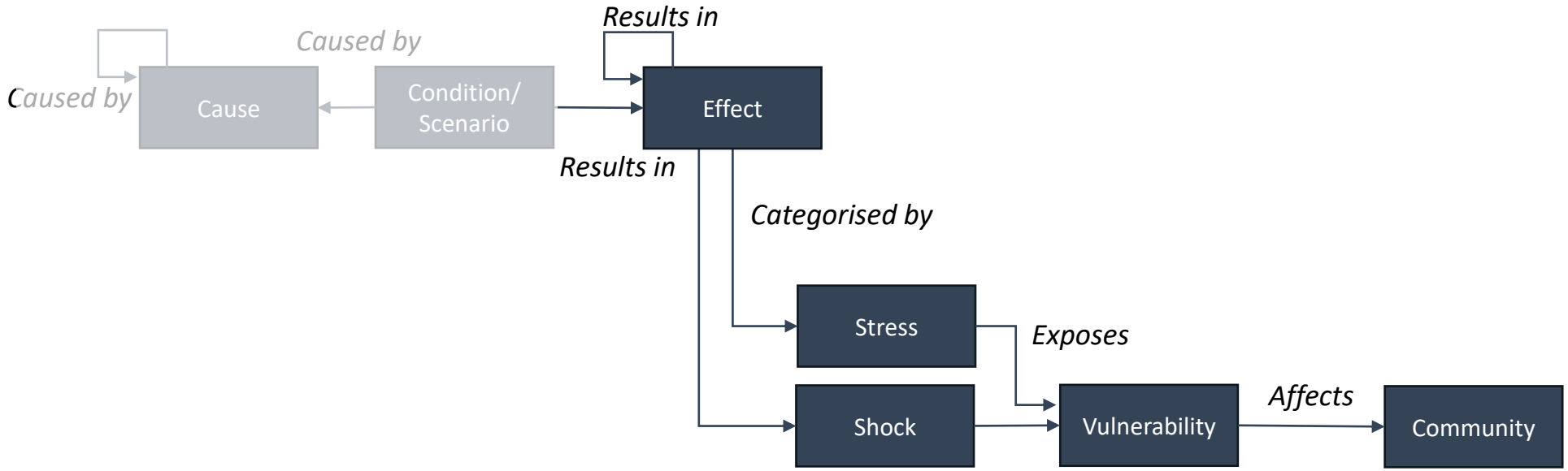
- Uncertain or unknown risk has no representative historical precedent
  - Difficult to frame scenarios around this
- Define scenarios that expose vulnerabilities identified during context definition



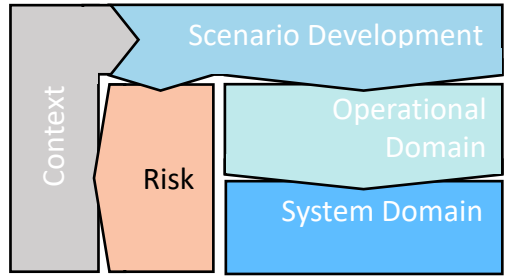
Explore Future Risk - what



- Workshop scenarios with stakeholders
  - Elicit mental models, pathways of cascading failure
- Provide a gauge of future risk severity and scale
- Understand and assess impacts to the **community**



Explore Future Risk - how



Context

Historical

Current

Future

Communicate & Iterate
future risk affects what will be valued in the future

Values, vulnerabilities, and exposures

Scenarios exposing vulnerabilities

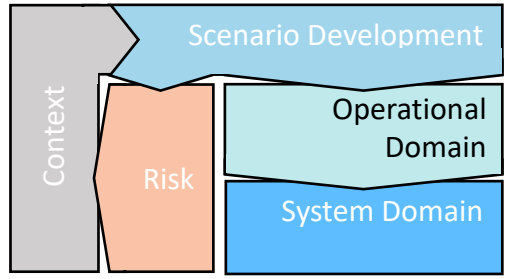
Mental Models

Cascading failures

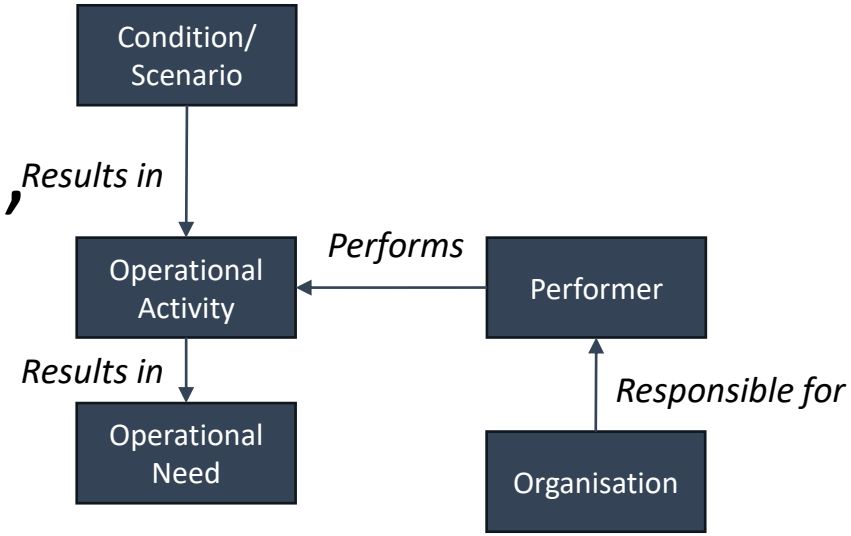
People and organisations affected

Is the capacity to cope exceeded?

Operational Domain

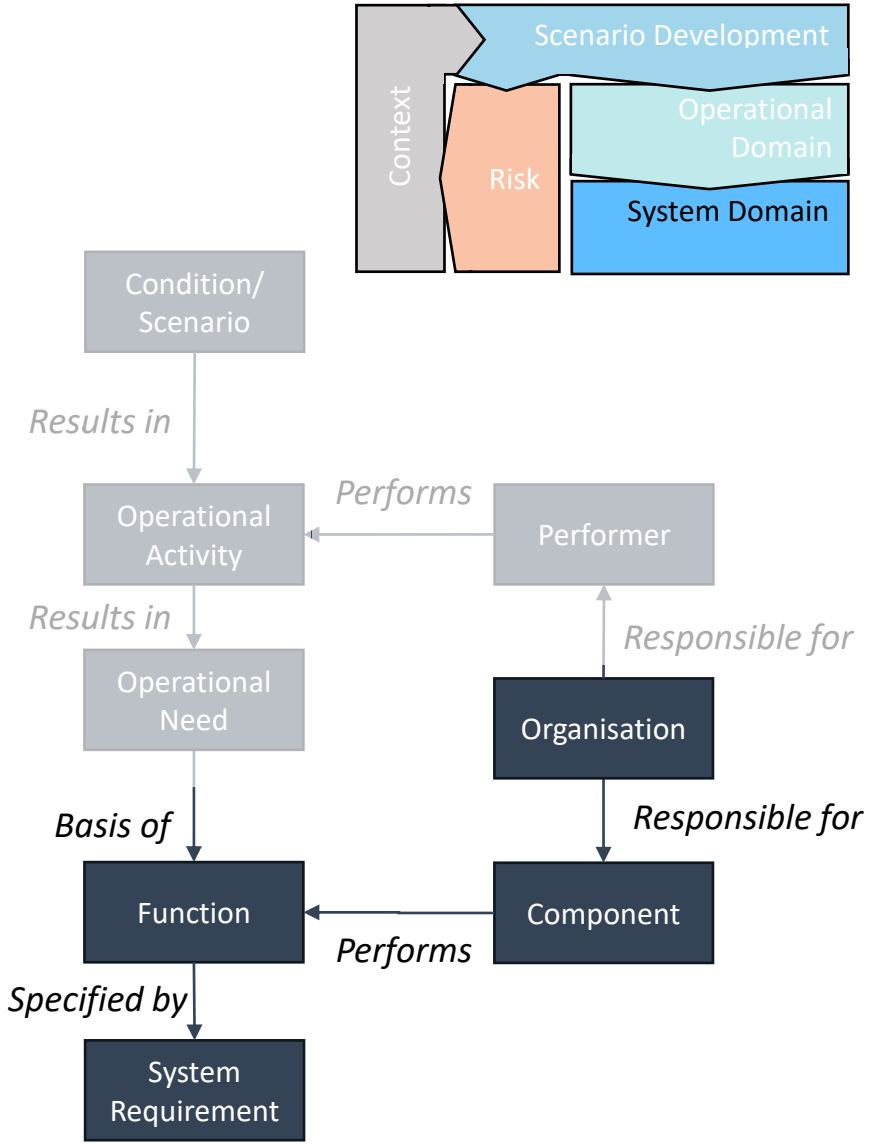


- Develop activities which describe the use of the system of interest under specified conditions
- Used to elicit needs of users, acquisition, development and support communities

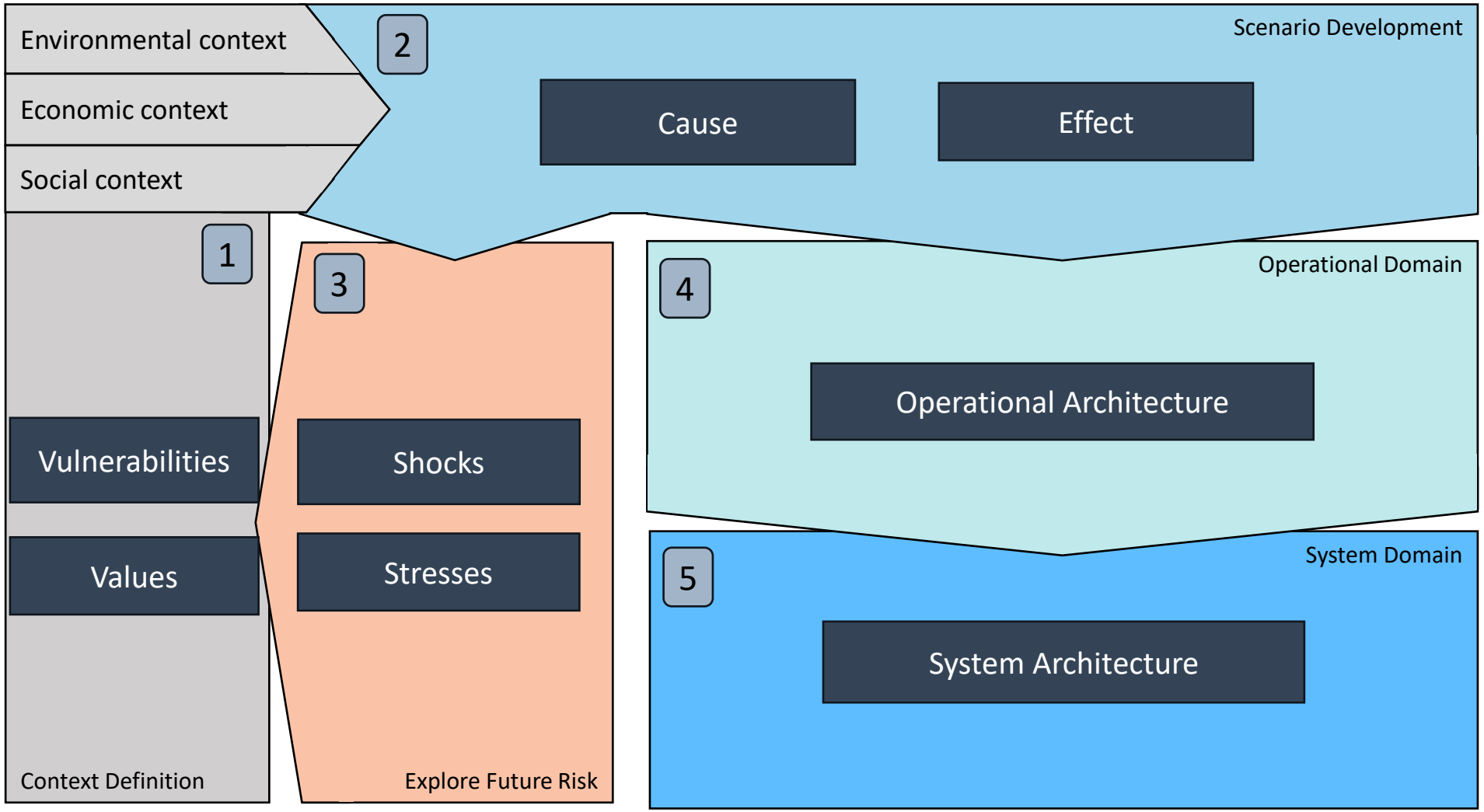


System Domain

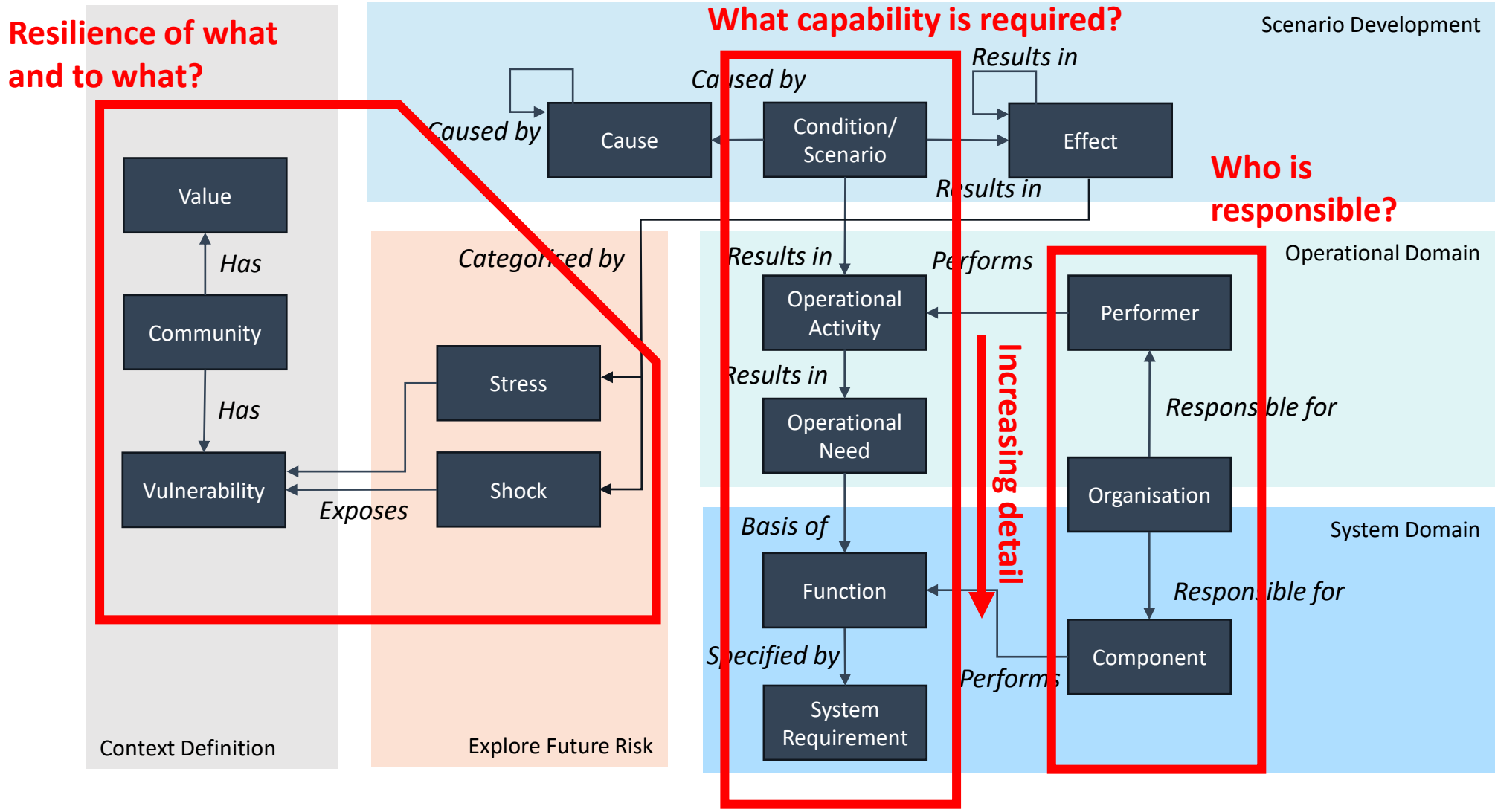
- Identify key capability components to deliver against the operational needs
- Decompose top level components to develop a more refined view of each element
- Components can
  - Perform functions
  - Be specified by requirements
  - Be delivered by an organisation



Process


Environmental context
Economic context
Social context
2
Scenario Development
Cause
Effect
1
3
4
Operational Domain
Operational Architecture
Vulnerabilities
Values
Shocks
Stresses
5
System Domain
System Architecture
Context Definition
Explore Future Risk

Schema


Resilience of what and to what?
What capability is required?
Scenario Development
Caused by
Results in
Cause
Condition/ Scenario
Effect
Who is responsible?
Value
Has
Community
Has
Vulnerability
Categorised by
Stress
Shock
Exposes
Results in
Performs
Operational Domain
Operational Activity
Performer
Results in
Operational Need
Responsible for
Increasing detail
Organisation
Basis of
System Domain
Function
Responsible for
Specified by
Performs
Component
System Requirement
Context Definition
Explore Future Risk

Conclusion

- Systemic risk poses a threat to Critical infrastructure
- Design for resilience requires understanding interrelationships and dependencies
- MBSE understand, decompose, and document complexity in system design
- Introduced a conceptual framework to
  - Identify points of leverage to increase resilience community resilience
  - Provide rigorous capability design early in the life cycle of critical infrastructure projects to ensure current and future needs are met

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Questions and comments

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