BIDIRECTIONAL COUPLING OF EARTH SYSTEM MODELS WITH SOCIAL SCIENCE MODELS: NEW MOTIVATIONS AND A PROPOSED PATH

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Four GSS Centers

INTEGRATED RESILIENCY ANALYSES

STRATEGIC SECURITY

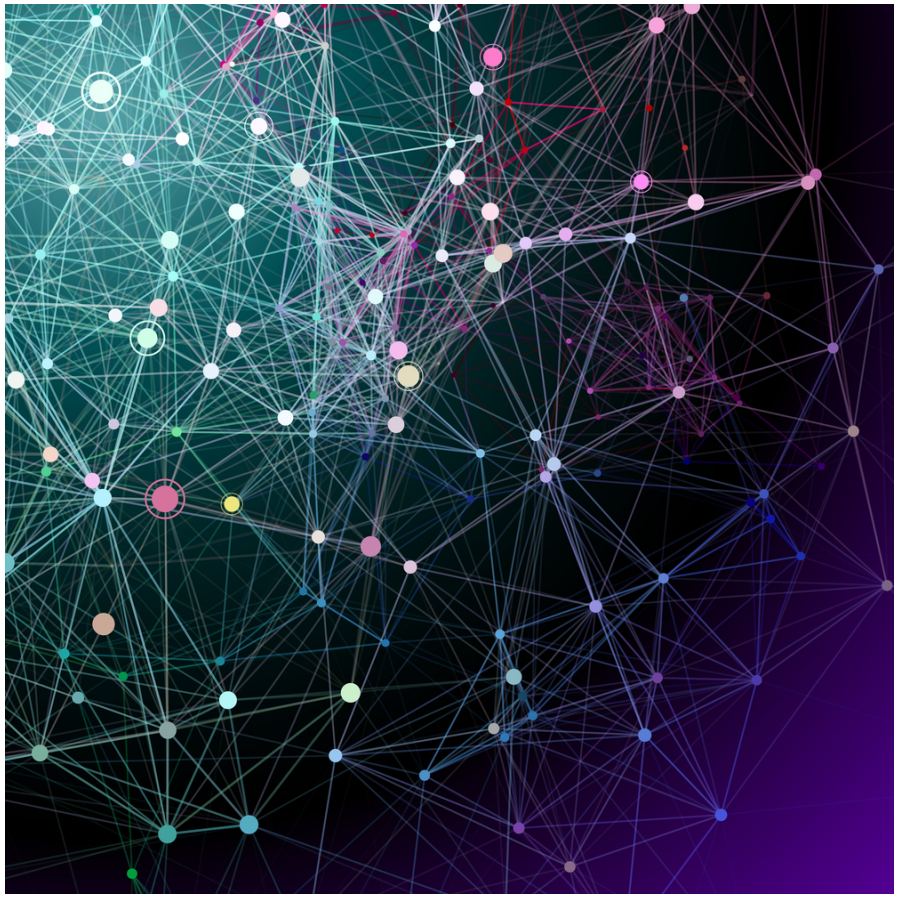
RISK AND INFRASTRUCTURE SCIENCE

SYSTEMS SCIENCE

WHAT IS A SYSTEM?

- ***A System*** is a set of interacting or interdependent components forming an integrated whole and serving a common purpose

- ***Systems Science*** is an interdisciplinary field that studies the nature of systems—from simple to complex—in nature, society, and science itself. The field aims to develop interdisciplinary foundations that are applicable in a variety of areas, such as engineering, biology, medicine, and social sciences.



APPLYING SYSTEMS SCIENCE

- Proven success in developing and delivering systems-based solutions to pressing problems in many areas, such as:
  - Energy security
  - Environment and natural resource contention
  - Social and cultural group interactions and conflict
  - Market behavior
  - Healthcare/health/infectious diseases
  - Logistics and supply chains
  - Aviation security
  - Trans-national and urban crime

MOTIVATION

CLIMATE CHANGE IS INCREASINGLY A FOCUS OF SOCIAL SCIENCE RESEARCHERS

Human life is a coupled natural-human system

- Humans are responding to a changing climate
- Natural resources that have led to the establishment of current ways of life are changing:
  - Droughts & changes in precipitation
  - Floods
  - Rising sea levels
  - Melting sea ice
  - Changing temperatures and growing seasons

- The way that humans manage, respond to, adapt to, or reorganize in the face of these challenges will be an important factor shaping life in the next several decades.

IMPACTS

Day-to-day life, but also national and global security, will be affected

US Army Corps of Engineers

ERDC

G. Understanding and/or Modeling How Human-Environmental Systems Influenced by Climate Change Contribute to Conflict/Stability (GRL 26)

The US Army increasingly is involved in military operations in locations where the natural environment is a contributing factor to conflict. Less is known about the potential role the environment plays in facilitating stability. Additionally, US Army operations can either directly or indirectly cause environmental degradation, thereby introducing undesirable 2nd and 3rd order effects. Exacerbating these problems are the increased ferocity and frequency of weather events and climate change. These problems constitute what is known as a "wicked problem", and how to operate in such an environment has been examined in Army doctrine, specifically FMs 3-0 and 5-0. PAM 525-5-500 also discusses the "wicked problem" and the need to look at the battlespace from a systemic perspective. Despite the discussion, the challenge of teasing apart these problems remains. When dealing with complex problems cause and effect cannot be established. There are causes and effects, which operate at various spatial and temporal scales. We are seeking novel approaches to address one or more of the following topics with regard to Human-Environmental systems influenced by climate change and conflict/stability: All approaches must address spatio-temporal variables and relationships.

CHALLENGE

FEEDBACKS ARE BIDIRECTIONAL

Current approaches do not capture truly bi-directional feedbacks

- Integrated Assessment Models
- Representative Concentration Pathways
- Shared Socioeconomic Pathways

- These are high-level characterizations that assume paths for the human system and examine the impacts on the climate

- These are useful (and necessary!), but not complete for many purposes
- Understanding the bidirectional feedbacks is key to addressing many questions in the 5-50 year time frame

OPPORTUNITY

Argonne NATIONAL LABORATORY

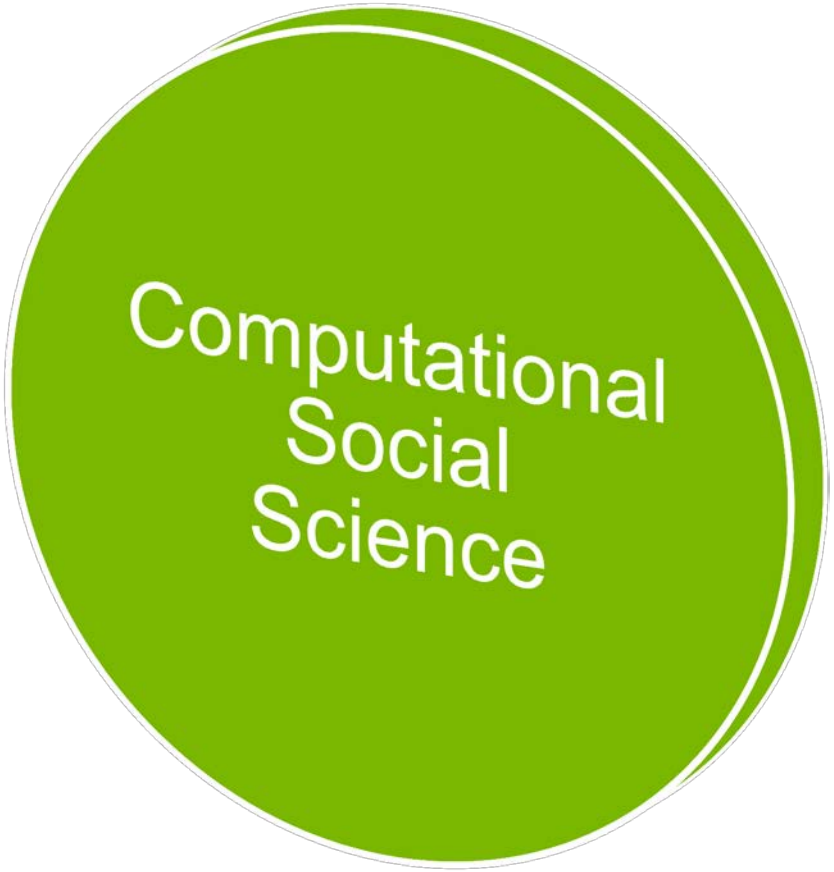
COMPUTATIONAL SOCIAL SCIENCE

Current social science approaches offer new paths forward

- Computational Social Science is a rapidly advancing field
  - Growing in scale to global sizes
  - Growing in theoretical sophistication and reach
  - Data sets are being compiled that support these

COMPUTATIONAL SOCIAL SCIENCE

Current social science approaches offer new paths forward



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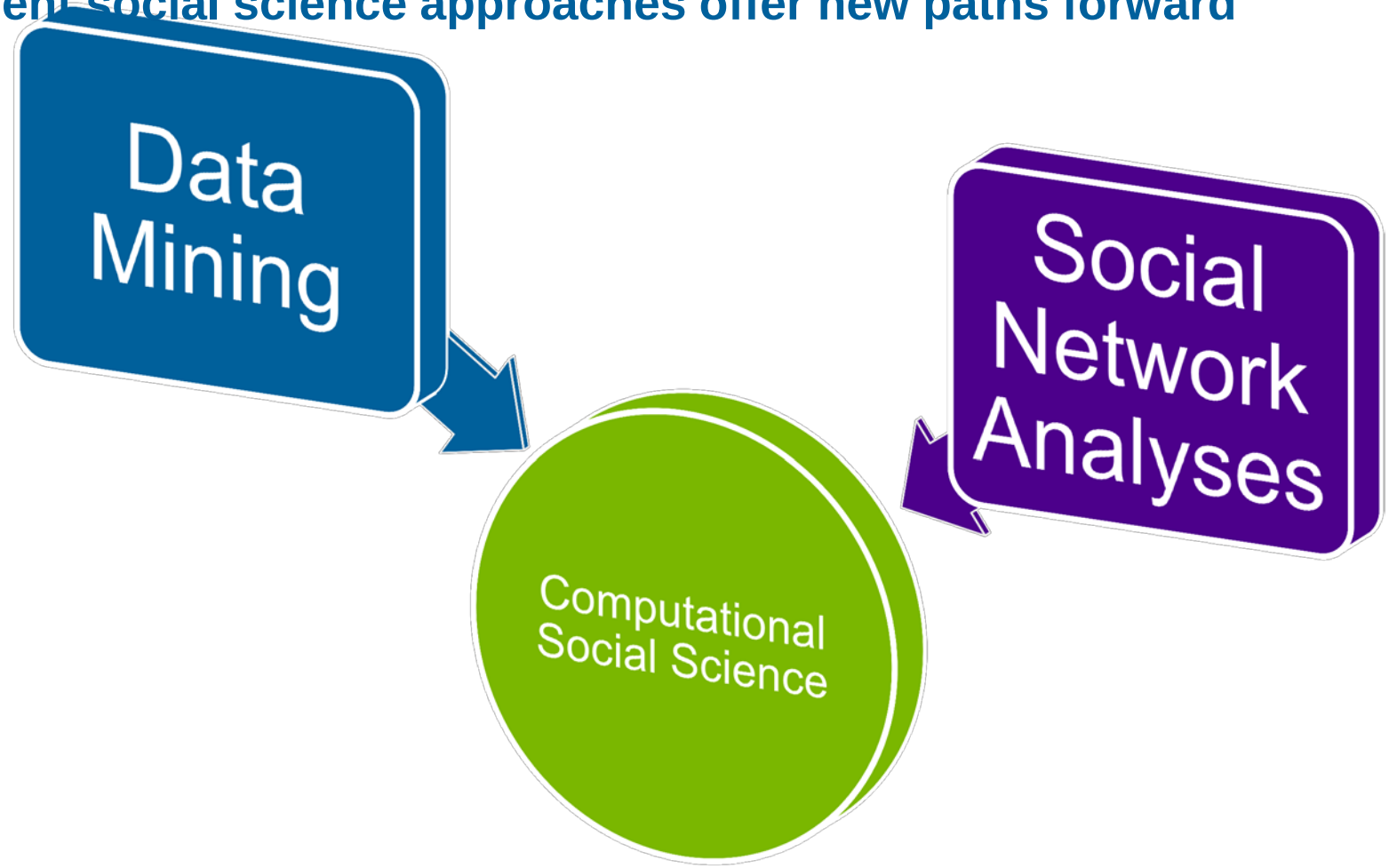

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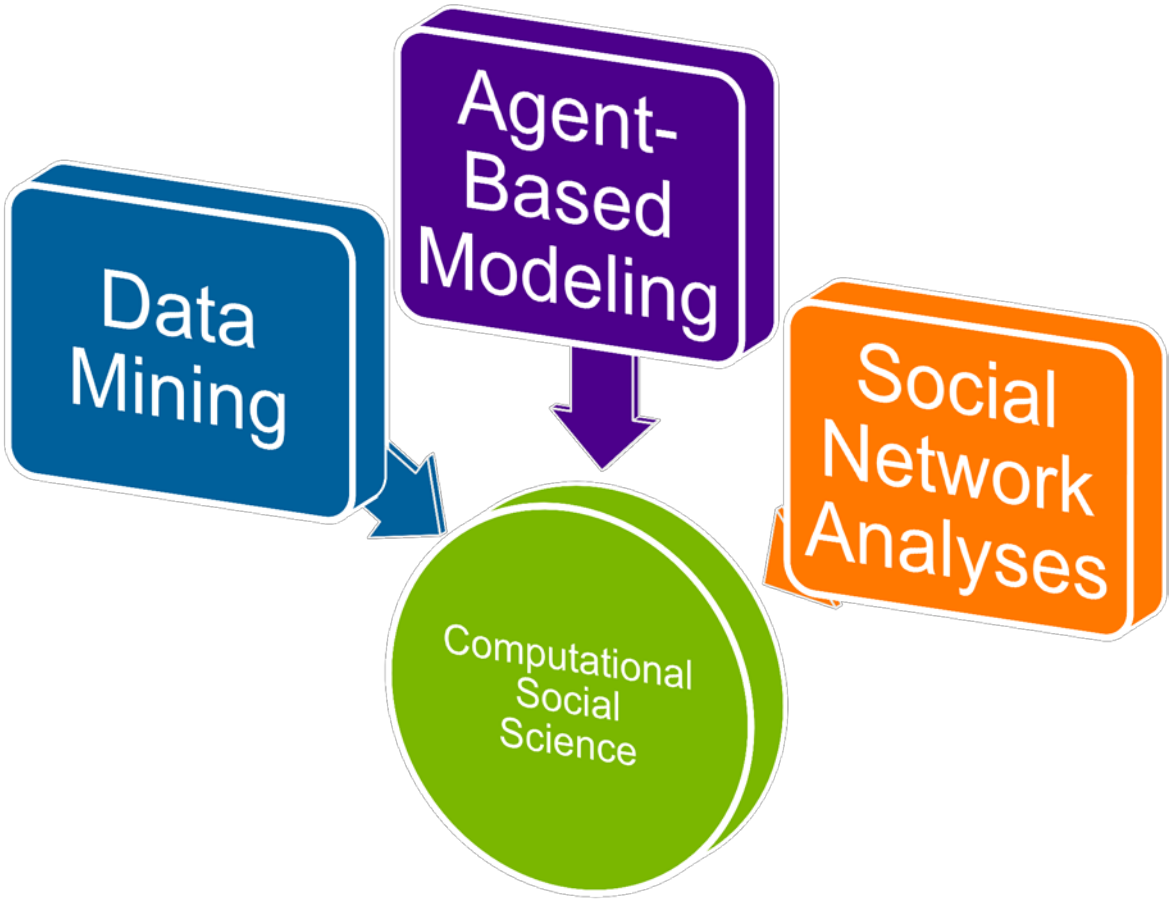


AGENT-BASED MODELS

Model individual attributes, decisions, and actions

- Agent-Based models are increasingly used in the social sciences
- Do not assume homogeneous actors; deal with real-world heterogeneity and complexity

- ABMs are increasing in scope and scale, and can now simulate *billions* of agents.

SIMULATION AT SCALE

Simulating every individual in the world is now possible

- Recent work by ORNL and ANL (Park et al. 2015) has linked GCAM and Repast HPC
  - Repast HPC = High Performance Computing version of Repast Agent-Based Modeling System
- Agents are located based on LandScan data and represent 7billion+ individuals

LIMITATIONS

Large scales now computationally possible, but theoretically difficult

- Link to GCAM one-directional
  - Time scales are different
  - Spatial resolution is different

- Theoretically difficult to justify simulating 7 billion individuals
  - Data are lacking
  - Hard to generalize

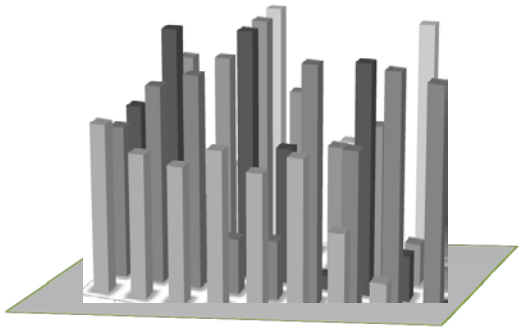
- However, global scale social simulations needn't take this approach

PROPOSED STRATEGY

CITIES AS THE FUNDAMENTAL UNIT

Why choose to focus on cities?

- Cities are the central drivers of the human system in the 21st century
- Data on cities widely available
  - ‘Smart Cities’ & sensors
  - Data portals
- Cities are being modeled in a wide variety of ways:
  - Scaling studies (Bettencourt, West)
  - Agent-Based Models of entire populations (Macal, ANL)
  - Traffic Simulations
  - Economic Models (Park et al.)
  - Real Estate Markets (Filatova, Gilligan)
  - Energy Consumption (LakeSIM)
  - Etc.



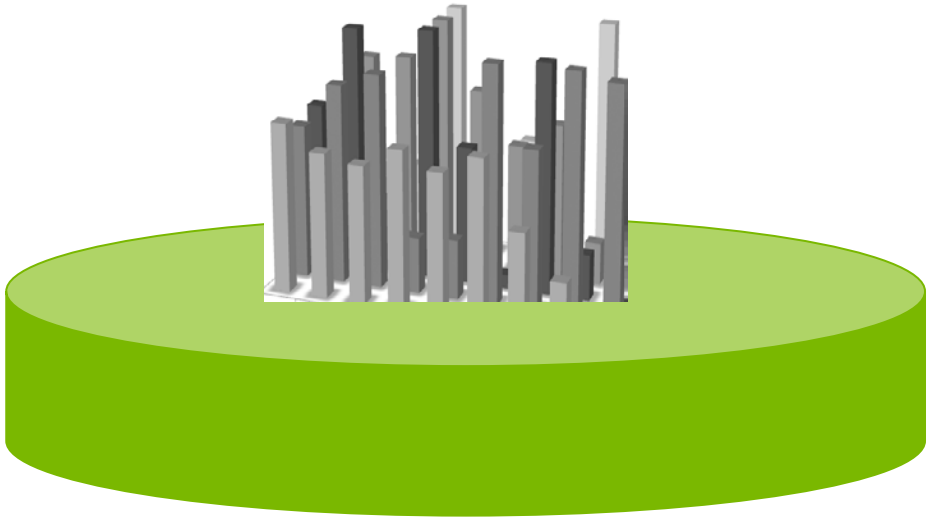
LANDSCAPES

Cities are connected to their surrounding landscapes

Cities draw resources (and people) from their surroundings.

Resources that are not easily portable (like water) are especially likely to be locally used

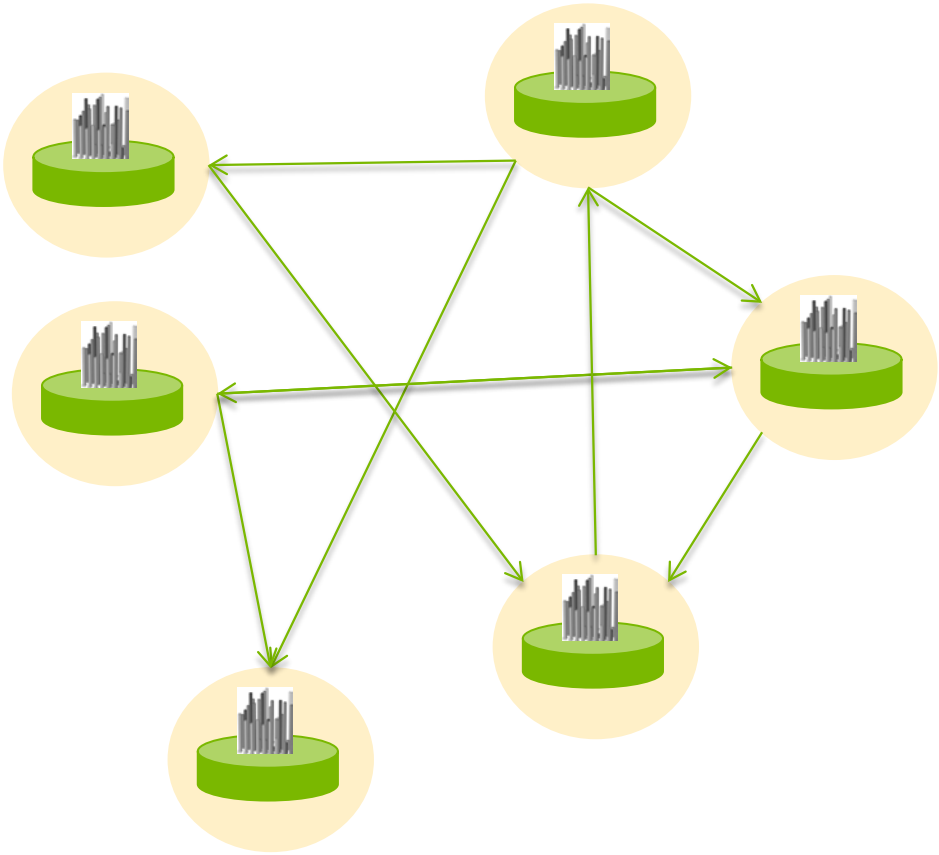
Cities emit products (waste, pollution) to their surrounding areas



NETWORKS OF CITIES

Cities are also disconnected from their local landscapes, but highly connected to other cities

- Cities are connected in networks of exchange
- This network is highly complex, but there is also rich data



BIDIRECTIONAL IMPACTS

The human system and the climate impact each other

HUMAN->CLIMATE

- Greenhouse gas emissions
- Changes to landscape, including reflectivity
- Diversion of water

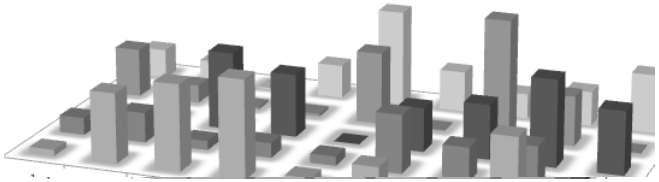
CLIMATE->HUMAN

- Temperature
- Growing Season
- Sea Level/Ice
- Precipitation/Drought/Flood
- Violent Storms

ADAPTATION

The City-Landscape-Network provides ‘axes’ for adaptation

- Cities can change internally



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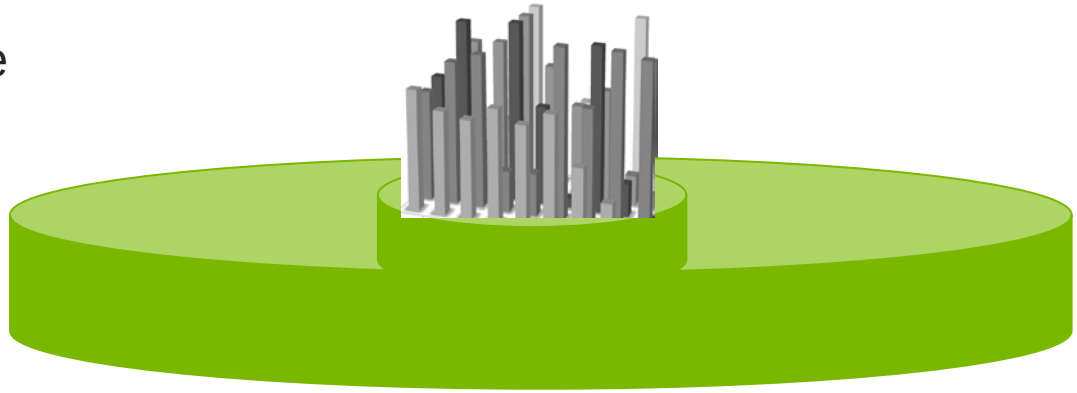
The City-Landscape-Network provides ‘axes’ for adaptation

- Cities can change internally

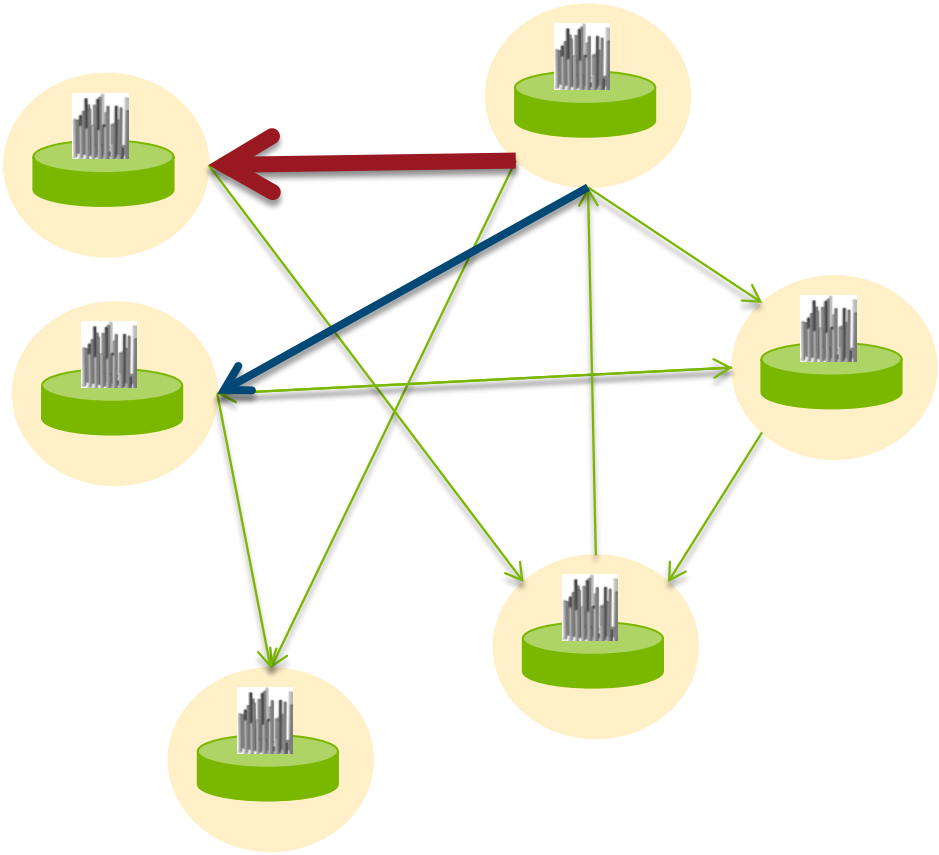
- Cities can change their connections with the landscape



ADAPTATION

The City-Landscape-Network provides ‘axes’ for adaptation

- Cities can change internally
- Cities can change their connections with the landscape
- Cities can change their connections in the network



TECHNICAL STRATEGY

Multi-year project, extensible design

- This project would not begin by simulating specific cities.
- Instead, an open-ended, extensible software strategy would be appropriate:
  - An initial mock up of a network of cities would be used to begin initial calibration
  - ‘Template’ cities in limited numbers of classes would be used at first
  - Flexibility to work with researchers in specific cities (with better data) when available
  - Only add complexity when necessary

INTEGRATION WITH CESM

- What would be the technical issues with linking the cities-landscapes-network representation with CESM?

  - ‘Channels’ through which the systems interact?
  - Scheduling events and matching time scales
  - Make sure that it does not replicate other aspects of the human system already captured in CESM
  - Other?

THANKS!

Reference

Park, Byung H., Melissa R. Allen, Devin White, Eric Weber, John T. Murphy, Michael J. North, and Pam Sydelko. MIRAGE: A framework for data-driven collaborative high-resolution simulation. *GeoComputation* 2015 Richardson, TX, USA, May 2015