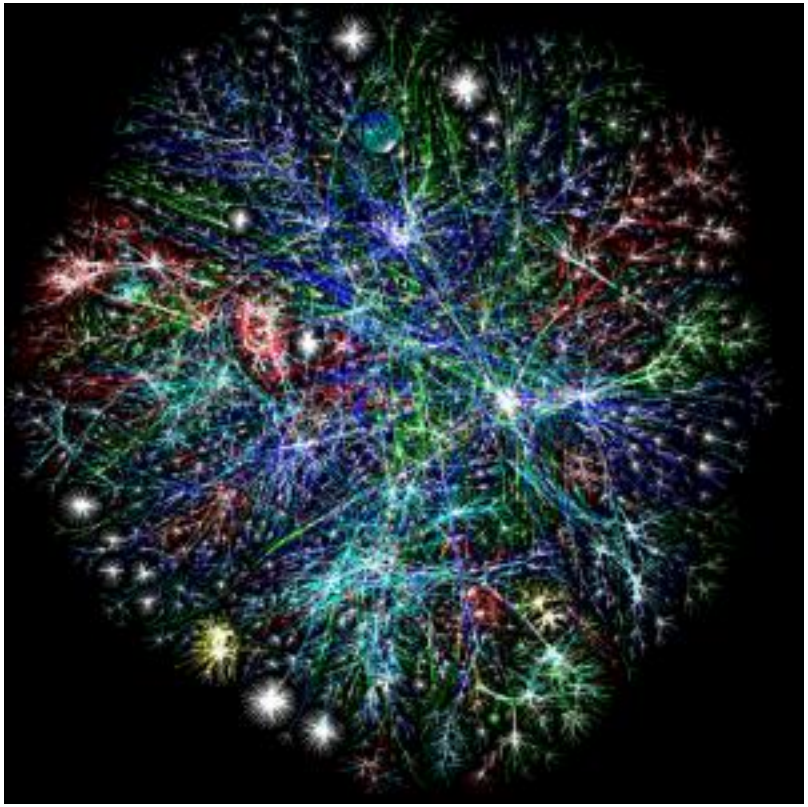
New Mathematically-based Tools of Systems Analysis and Related Decision Support Applications



Credit: commons.wikipedia.org

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Challenges for Systems Analysis and Decision Support

- Decision makers in fields from engineering to medicine to ecology have available remarkable new mathematically-based tools of systems analysis.
- Applications to problems of the planet are spurred by dramatic amount of data available & remarkable tools for using data to make better decisions & influence policy.
- Yet applying these tools presents complex new challenges.

Fusing Many Sources of Information

- How to use data from a wide variety of sources for better decisions?
- ***Tools of Mathematical Modeling & Simulation*** can help.
- In 1900, only 13% of the world's population lived in cities. By 2050, it is predicted that 70% will.
- Climate change has serious effect on urban areas: more severe hurricanes, heat waves, droughts, ...
- During "Super Storm" Sandy in 2012, subway tunnels in New York City were flooded.
- Fusing data from many sources, mathematical models developed at Columbia University predicted which ones.
- Can we use similar models to predict effects of sea level rise in urban areas?
  - Which power plants, train tracks to move

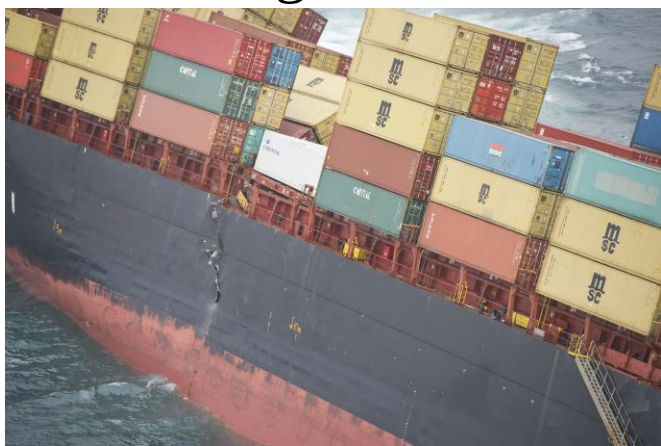
Fusing Many Sources of Information

- Health of ecosystems can be obtained by measuring **biodiversity** – variability of plants and animals.
- ***Tools like Artificial Intelligence and Machine Learning*** are helping to identify species.
- **Snapshot Serengeti**: Motion-sensor cameras ("camera traps") have collected millions of images of lions, leopards, cheetahs, elephants. 3.2 million images.
- They launched an app that uses deep convolutional neural networks to identify and count species - system is accurate 93.8% of the time.
- Next step: Identifying individual animals.

Source for all: Fred Roberts

Fusing Many Sources of Information

- Supply chains are increasingly interconnected.
- The recent blockage of the Suez Canal by a grounded container ship continues to affect supply of oil, food, microchips to make cars, availability of empty containers, etc.
- ***Tools like Multi-agent Simulations*** have been used to simulate supply chain operations and the interactions among "players."
- Each player is an "intelligent autonomous agent" and can process multiple events and subproblems.
- Such simulations allow for prediction of impacts of disruptions and the impact reduction of different mitigation strategies.



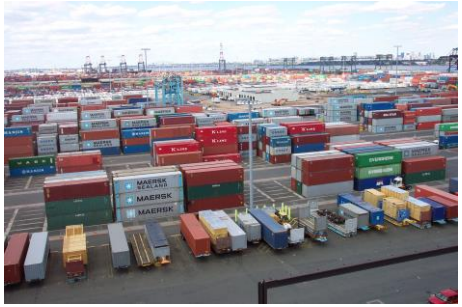
Credit: Wikimedia commons: New Zealand Defence Force

Fusing Many Sources of Information

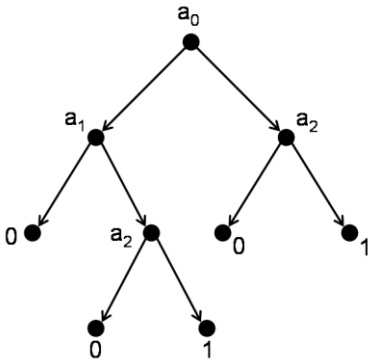
- With climate change, there is more vessel traffic in the Arctic and possibility of offshore oil drilling
- Increased risk of spills from vessels or drilling
- Arctic challenge: resource allocation for oil spill response
  - Challenging because of long transit times, lack of infrastructure, remote locations, lack of roads, distant airlift
  - Need data about existing equipment, transportation, communication, etc.
- ***Tools of Stochastic Programming*** have been used to allocate resources under uncertainty and budget constraints
  - What oil spill response equipment should be ”forward-located” in advance? Where to locate it?
  - What equipment should be prepared for “surge” deployment?
  - Near-term vs. long-term planning
  - Seasonal adjustments
  - Purchase vs. contract

Sequential Diagnosis

- In sequential diagnosis, there are a variety of tests available and you choose the next test on the basis of results of earlier ones.
  - Useful in medicine, manufacturing, communication networks, etc.
- ***Tools like Optimization & Decision Trees*** are helpful here.
- Example: One approach arose from inspecting containers at ports and has applications in education testing, disease testing, etc.
- Many kinds of tests. Want most efficient screening protocols.
- Difficulty: combinatorial explosion in number of possibilities.
- Represent possible tests as binary decision trees.
- Find "optimal" BDT.
- With 5 possible tests there are 263,515,920 possible BDTs.
- Search algorithms to move from one BDT to a better one hold hope for solutions.



Credit; en.wikipedia.org



Sequential Diagnosis

- Alternate approach to container inspection: SNSRTREE
- ***Tools like Large-scale Linear Programming*** are relevant.
- SNSRTREE allows for mixed strategies, accommodates realistic limitations on budget and testing capacity and time limits.
- Originally developed for testing for nuclear contraband.
- Recent research on using this tool to testing for COVID-19.
  - How to optimally select from available tests according to the person, the work they do, results of prior tests, dynamic test availability.
  - SNSRTREE finds the entire set of "optimal" testing policies for all possible budgets.

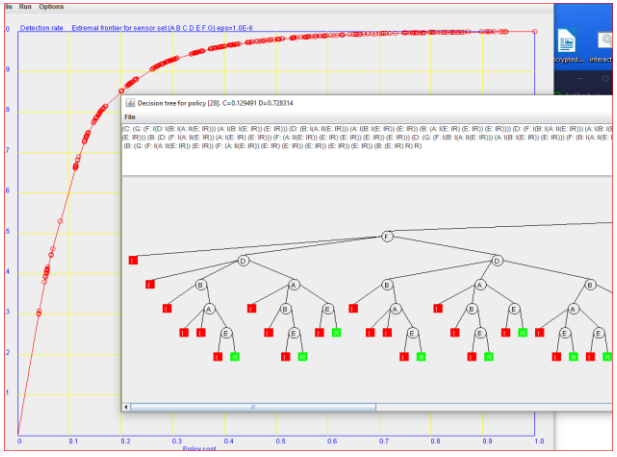


Photo credit: Wikimedia Commons, National Cancer Institute, John Keith photographer

Data-driven Decision Science

- Decision science is a key part of systems analysis.
- What is new is that modern data-driven decision science can allow comparison of a vast array of alternative solutions.
- ***Tools of Algorithmic Decision Theory (ADT)*** aim to exploit algorithmic methods to improve decision maker performance.
- The 2014 Ebola outbreak in West Africa should have reminded us that the world is ill-prepared for a severe disease epidemic.
- When COVID-19 hit, the world was indeed poorly prepared.
- Successful fight to contain Ebola outbreak was helped by ADT.
  - Accurately predicted disease spread and how to contain it.
  - Data allowed decision makers to understand things like: how many beds and lab tests would be needed — and where and when to deploy them.
- During COVID, numerous models & simulations aided by a tsunami of shared data have aided decision makers to save lives.

Credit: Doctors Without Borders

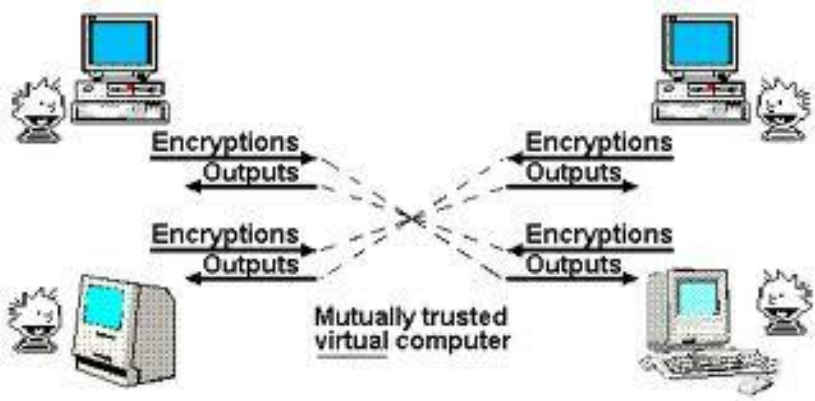
Data-driven Decision Science

- Supply chains have been dramatically changed in the digital age.
- Artificial intelligence and machine learning have allowed the private sector and governments to minimize inventories.
  - Due to extremely accurate knowledge of demand for goods or components.
  - Allowing for ”just-in-time” delivery.
- COVID has demonstrated the problems with this approach.
  - Shortages of medical equipment (ventilators, masks)
  - Shortages of consumer goods (toilet paper, disinfectant wipes)
- ***Tools of Algorithmic Decision Theory*** are a key to making supply chains better prepared for natural disasters and more resilient:
  - Modified ML tools to identify alternative sources and change priorities in a speedy way.
  - Data-driven decision making to support decisions about stockpiles for natural disasters, alternative suppliers, modified transportation routes.

Image credits: Left: Laurie Kolano; Right: Wikimedia commons, Timely Medical Innovations, LLC

Information Sharing

- Information sharing is a key to enable all kinds of organizations and individuals to work together while protecting their private information.
- It has become a major research area in tools for systems analysis.
  - Example: sharing information in multinational partnerships for sustainable development in transboundary river basins
  - Example: sharing information about energy use in homes while maintaining privacy
- ***Tools of Secure Multiparty Computation*** comprise a theoretical area aiming at allowing parties to jointly compute something over their inputs while keeping those inputs private.
- ***Blockchain is a Tool that provides*** a decentralized recordkeeping system that enables disparate parties to transact safely without needing a middleman.



Information Sharing

- To utilize the vast amounts of information available to us, we have to understand what sources we can trust.
  - Example: Disaster situation; lots of data as to damage, physical needs, information needs, etc. What to trust?
  - Example: Shared information about water quality; air quality; flood risk
- ***Tools called Trustmarks*** are digitally signed assertions by a third party assessor; shared between parties seeking to share information.
  - Provide evidence that an individual sharing information meets trust requirements.

Japanese Earthquake & Tsunami; credits: commons.wikipedia.org and www.flickr.com

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Information Sharing

- Proving your identity is part of information sharing.
- So is proving you have the authority to do something.
  - Prove you have been vaccinated so you can board a flight
  - Prove that you have emergency medical training so that you can help after an earthquake or hurricane
  - Prove that you are allowed to be in a remote wilderness area to study endangered species
- ***Tools of Identity and Access Management*** are being developed to enable individuals' smartphones to carry encrypted information about their credentials – to speed approval for giving them access.
- This too is an important, growing field of systems analysis that will help enhance trust in numerous situations.

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