Give me the place to stand: Leverage analysis in systemic design

RSD7: Models and processes of systemic design

Ryan J. A. Murphy and Peter Jones

October 24, 2018

MEMORIAL UNIVERSITY

OCAD UNIVERSITY

Three questions about systems models

- **(1) How might we balance the trade-offs of "soft" and "hard" systems thinking?**
  - Forrester (1994): "Systems thinking and soft OR […] rely on subjective use of unreliable intuition for evaluating the complex structures that emerge from the initial description of the real system."
  - Checkland (1984): "Systems engineering, based on defining goals or objectives, simply did not work when applied to messy, ill-structured, real-world problems."
- **(2) How might we handle complexity?**
  - Jones (2014): Representative maps include input from more stakeholders
  - Crowdsourcing (Lukyanenko & Parsons, 2012) and data science (Šćepanović, 2018) offer tools to support large-scale data collection
- **(3) How might we learn from these models?**
  - Models are excellent opportunities to find the most important actors/phenomena/structures in a system: "leverage points" (Meadows, 1999)

MEMORIAL UNIVERSITY

OCAD UNIVERSITY

Ways forward: borrowing from social network analysis and systems dynamics

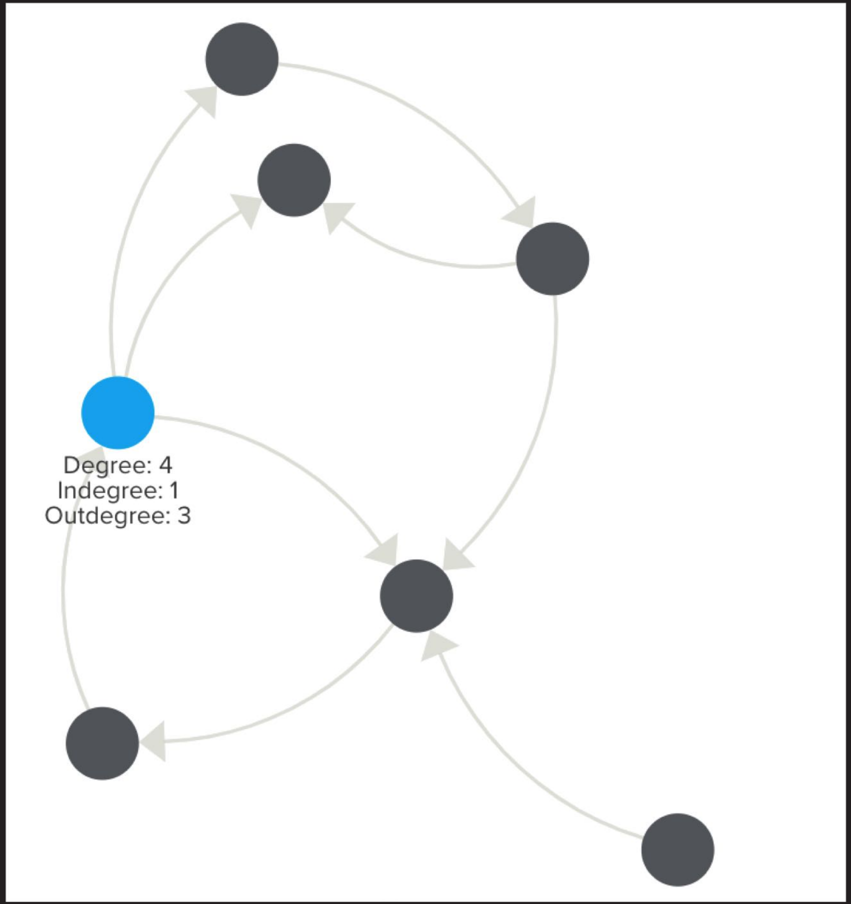
- **Many systems models (e.g., Causal Loop Diagrams) are *graphs***
  - – Formal definition: a set of vertices (the elements of the system) and edges describing a relationship between the vertices (e.g., connections between elements)
  - – Graph theory provides analytical methods for understanding graphs, such as:
    - Centrality analysis
    - Structural analysis
  - – These methods have *not* been applied to soft systems models

MEMORIAL UNIVERSITY

OCAD UNIVERSITY

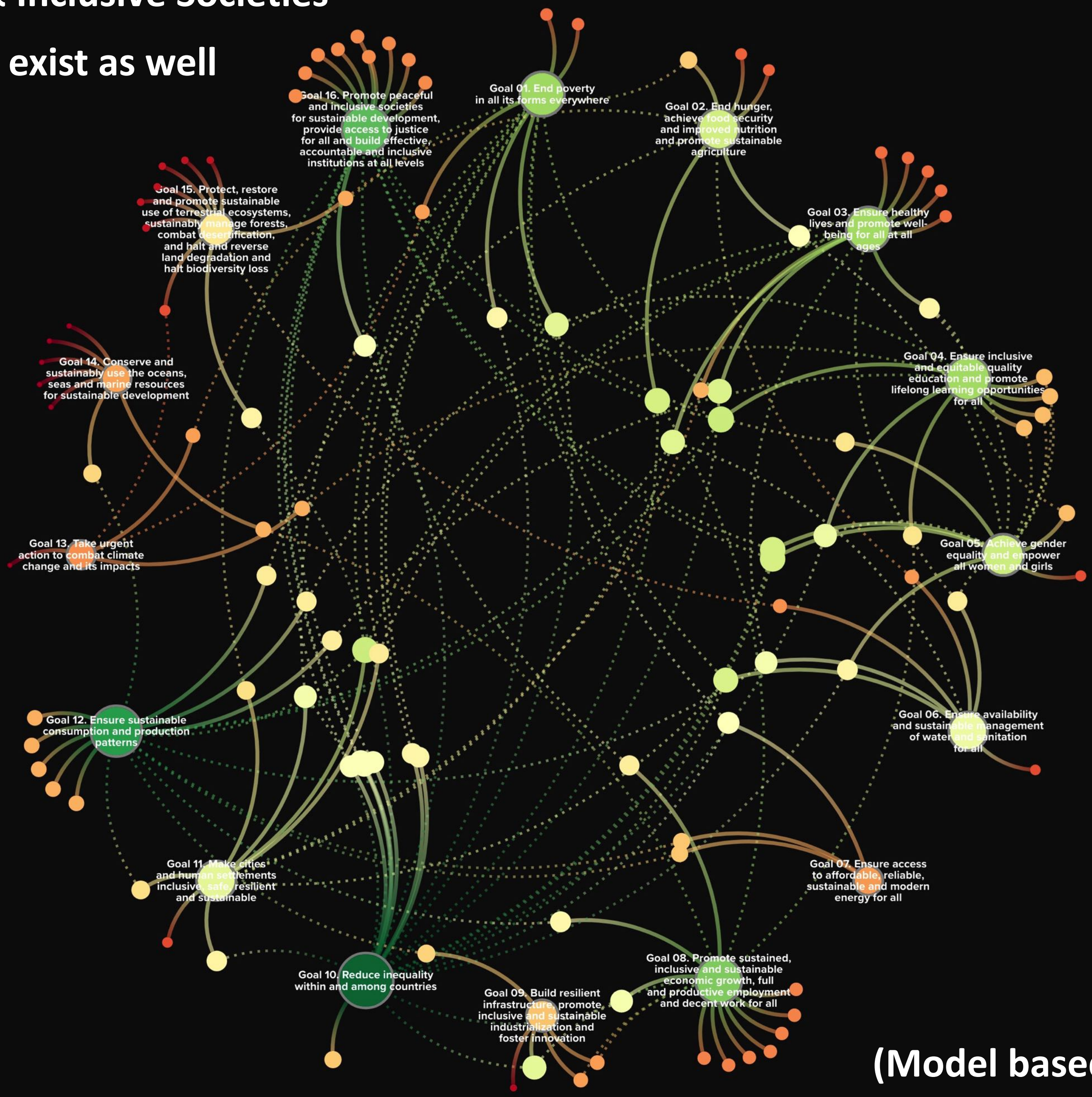
Example from centrality analysis: *Degree*

- **The number of connections of a given element (Newman, 2010)**
  - Indegree
    - The number of incoming connections.
    - An indicator of popularity
  - Outdegree
    - The number of outgoing connections.
    - An indicator of gregariousness



High-closeness SDGs: Inequality, Sustainable Consumption & Production, Peaceful & Inclusive Societies

High-closeness *targets* exist as well



(Model based on Le Blanc, 2015)

MEMORIAL UNIVERSITY

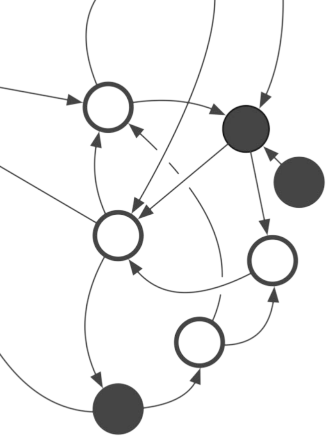
OCAD UNIVERSITY

Applying centrality and structural analysis to causal loop diagrams

Metric/Method	Description	In Social Networks	In Causal Loop Diagrams?
Degree	The number of connections	Higher connectivity to the rest of the network; influence, access, prestige (Newman, 2010)	Immediate impact, sensitivity, resilience
Indegree	The number of incoming connections	High inward connectivity to the rest of the network; sensitivity to information, influence (Newman, 2010)	Receives change from many other elements; may be highly volatile or highly stable
Outdegree	The number of outgoing connections	High outward connectivity to the rest of the network; rapid communication/high access to the rest of the network, highly infectious (Newman, 2010)	Change in the given phenomena is felt by many other elements; impact, power

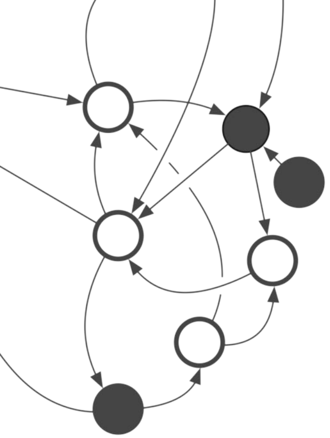
MEMORIAL UNIVERSITY

OCAD UNIVERSITY



Applying centrality and structural analysis to causal loop diagrams

Metric/Method	Description	In Social Networks	In Causal Loop Diagrams?
Betweenness	Frequency of participation in the shortest path between two other elements	Member has a high degree of control; the network is dependent on the member; bottlenecking, control, influence (Freeman, 1979)	Phenomena is a gateway or bottleneck for change; change strategies must consider how to prevent blocking
Closeness	Average length of the shortest paths between the given vertex and every other vertex in the graph	High visibility to the rest of the network and information spreads easily from this member; independence from the rest of the graph (Freeman, 1979)	Phenomena is highly powerful; likely to be resistant to change, and therefore a key indicator of success or failure
Eigenvector	Connectedness to other well-connected elements	Influence of highly influential elements; influence (Newman, 2010)	High-impact phenomena; likely key phenomena to change in pursuit of a given strategy



Applying centrality and structural analysis to causal loop diagrams

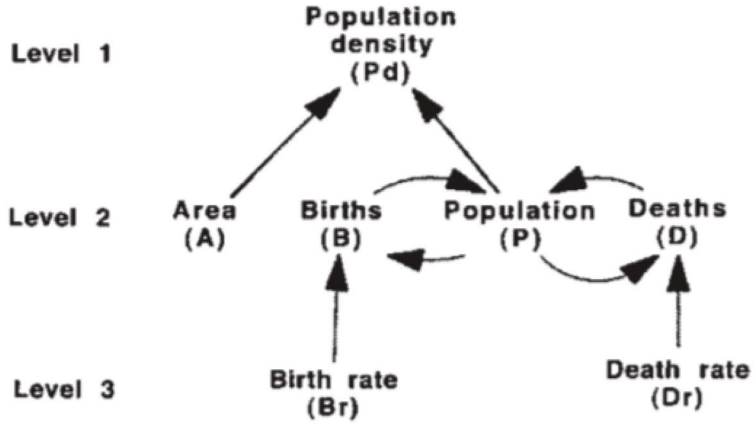
Metric/Method	Description	Social Networks	In Causal Loop Diagrams?
Reach	The number of elements within [x] steps of the given element	Quick propagation of information through the network; widely accessible (Hanneman & Riddle, 2005)	The map is highly sensitive to these elements
Reach efficiency	The reach divided by the degree of a given node	Efficient (non-redundant) information spreading; high exposure with limited influence on the given element (Hanneman & Riddle, 2005)	Quickly and efficiently propagate change throughout the rest of the network; is not likely to be highly influenced by the rest of the system

Example from structural analysis:
Level partitions

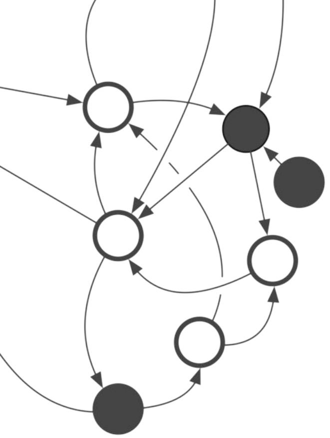
Fig. 5. Adjacency matrices block ordered by levels

(a) Model in Figure 1

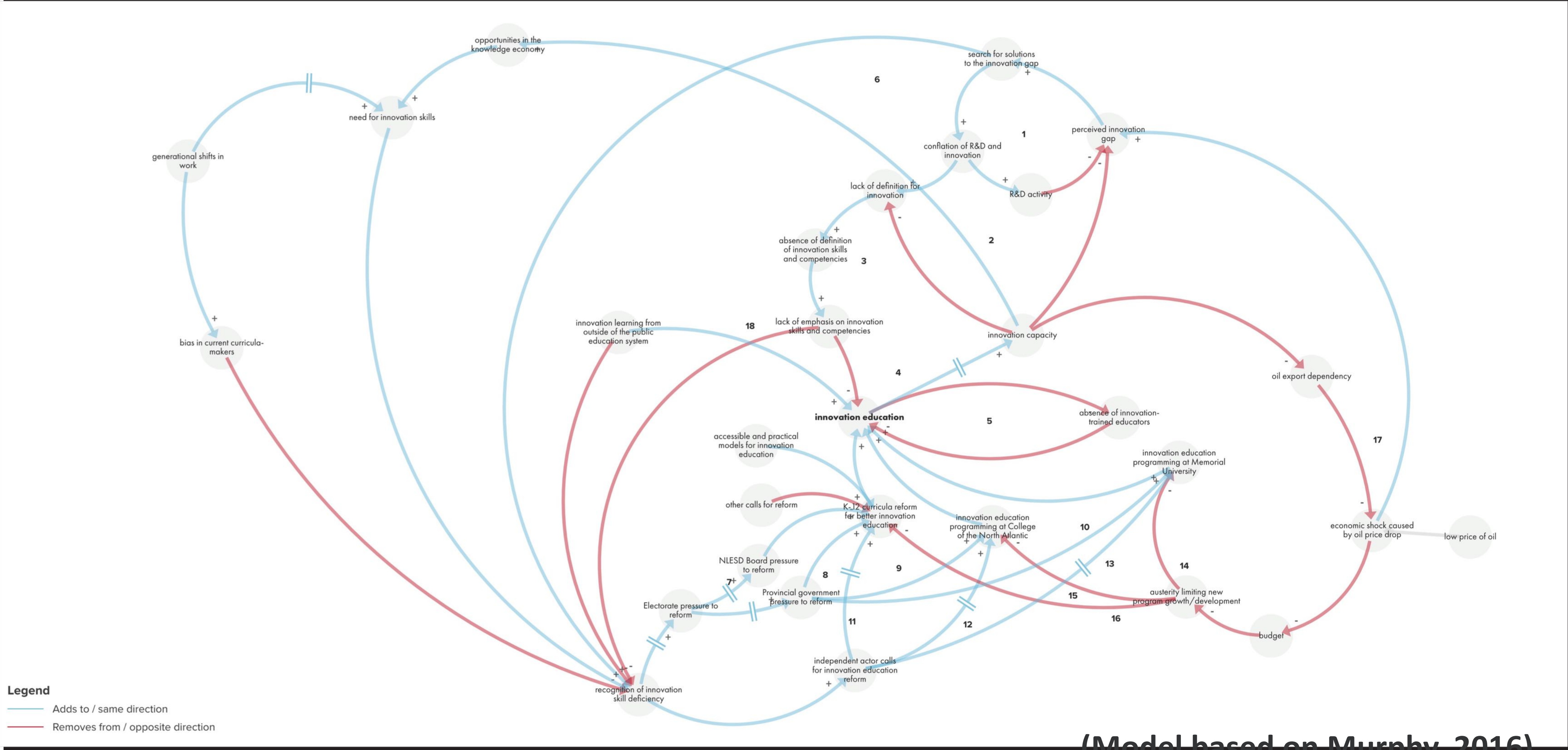
		Pd	A	P	B	D	Br	Dr
L1	Pd	0	0	0	0	0	0	0
	A	1	0	0	0	0	0	0
L2	P	1	0	0	1	1	0	0
	B	0	0	1	0	0	0	0
	D	0	0	1	0	0	0	0
L3	Br	0	0	0	1	0	0	0
	Dr	0	0	0	0	1	0	0



(Oliva, 2004)



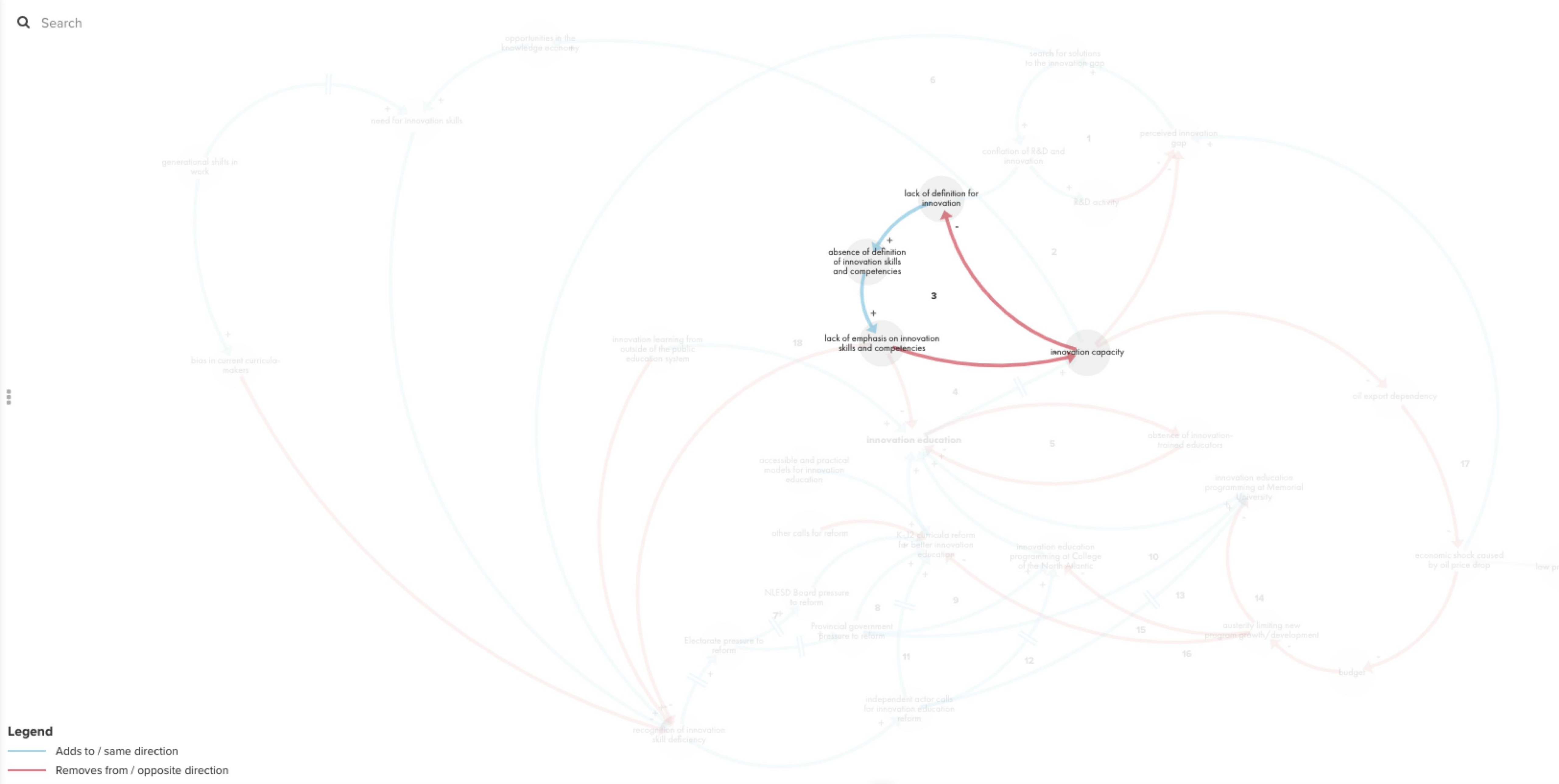
Example: Education systems change

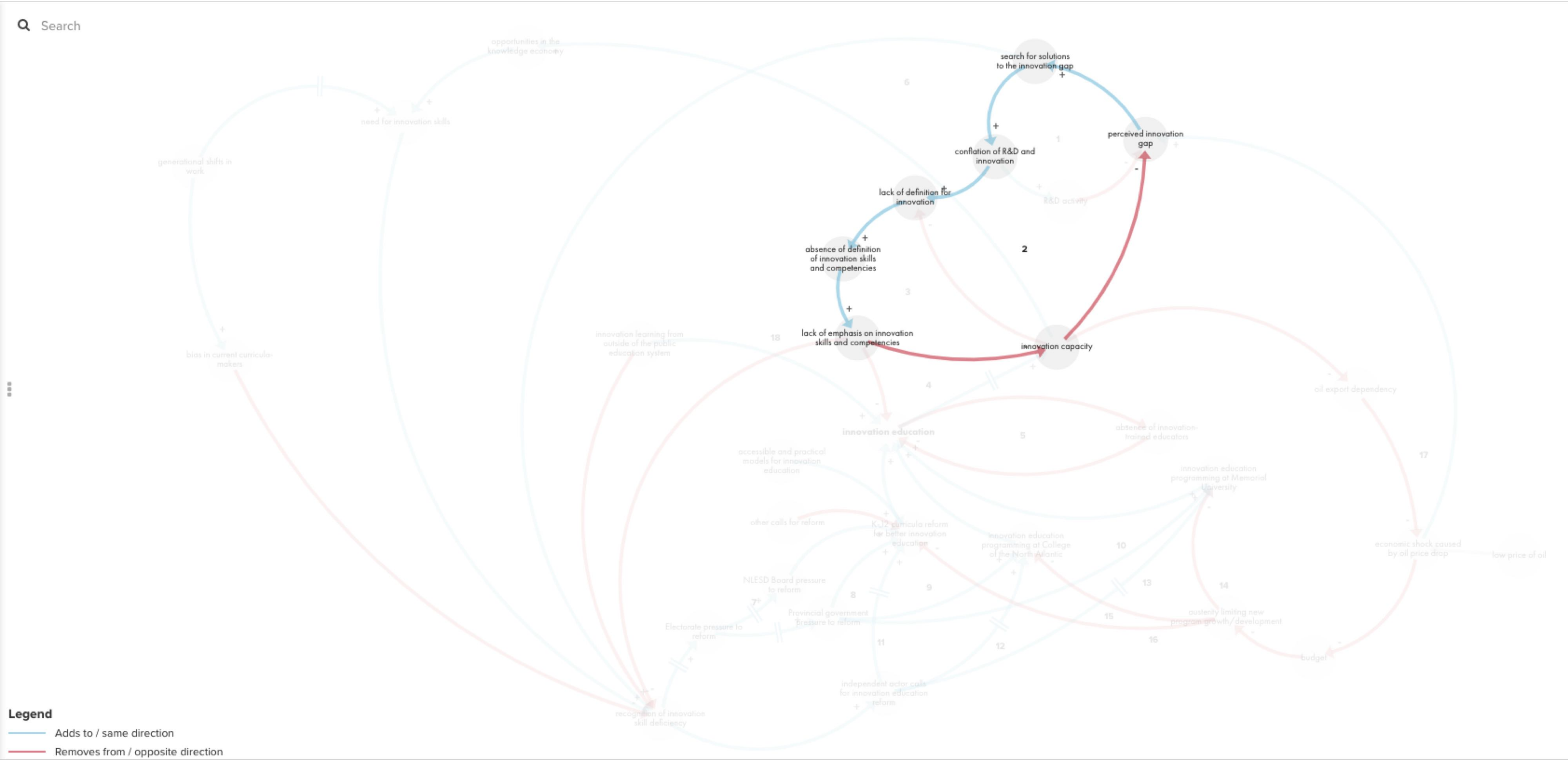


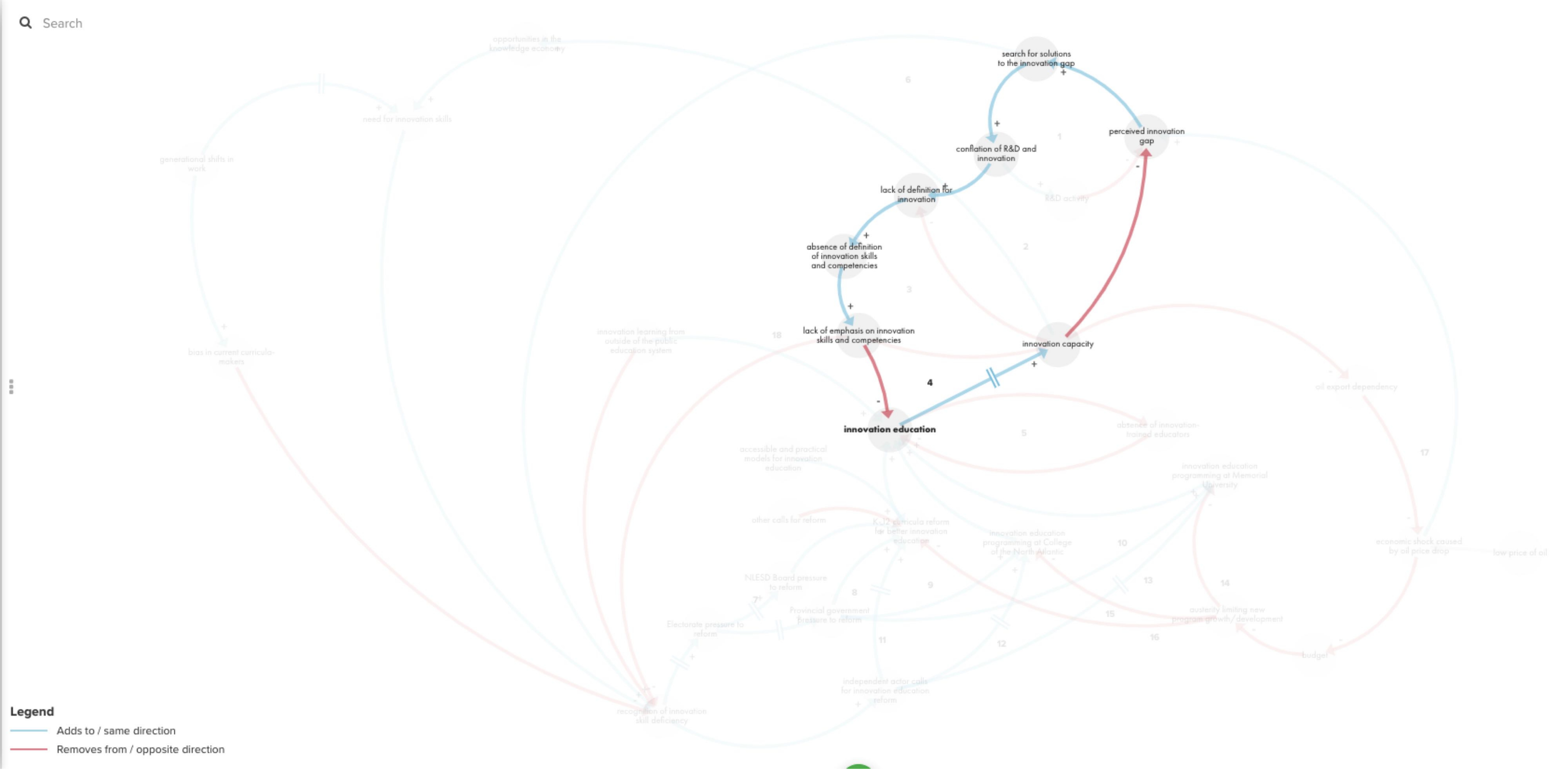
(Model based on Murphy, 2016)

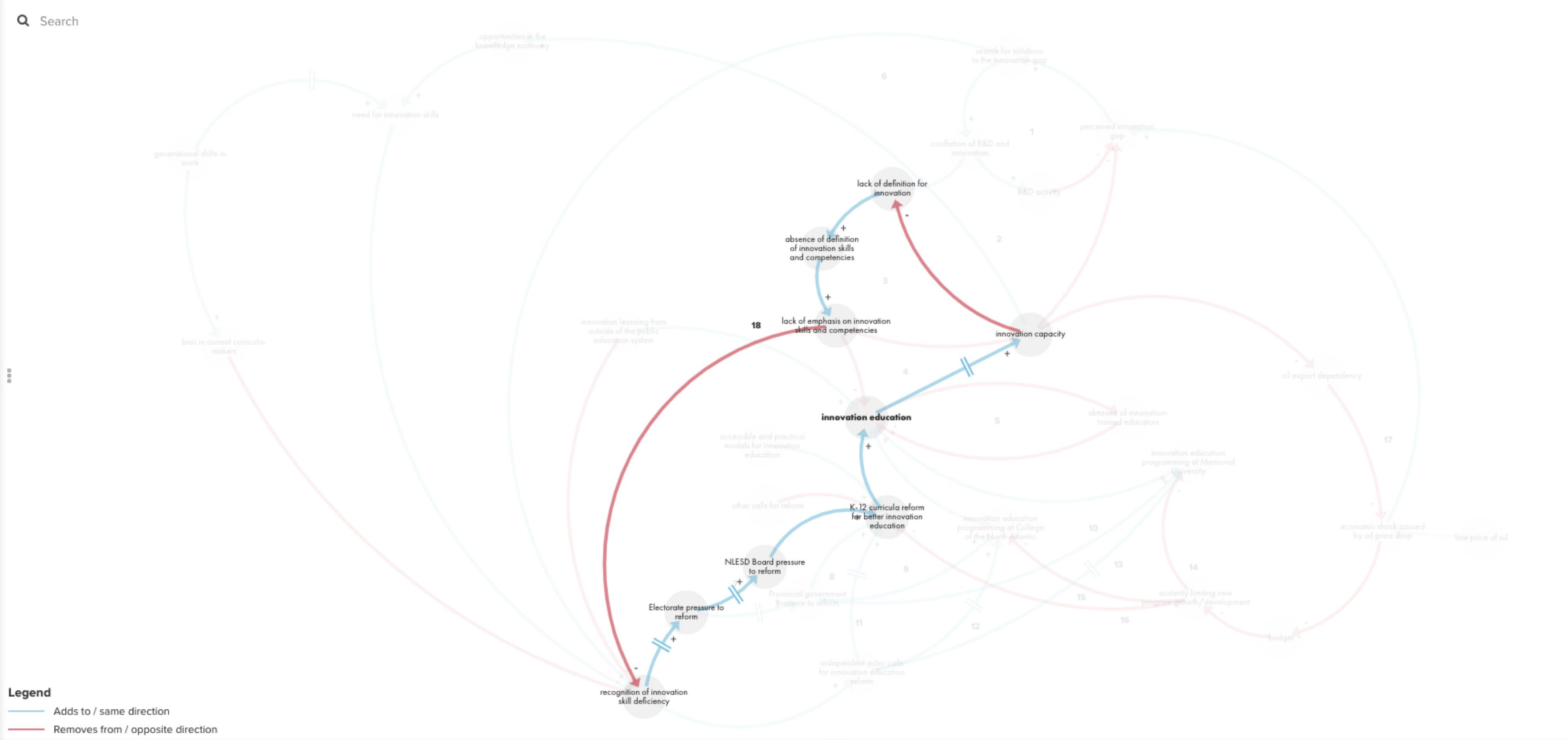
Example: Education systems change

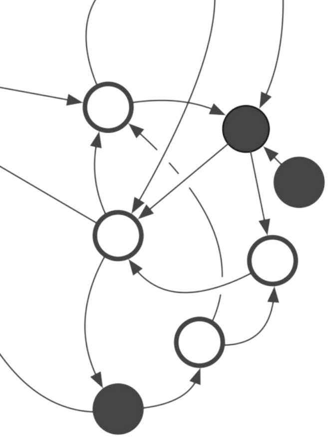
- Level partition only results in two levels
- Loop inclusion graph:


Search
lack of definition for innovation
absence of definition of innovation skills and competencies
lack of emphasis on innovation skills and competencies
innovation capacity
3
Legend
Adds to / same direction
Removes from / opposite direction


Search
search for solutions to the innovation gap
perceived innovation gap
conflation of R&D and innovation
lack of definition for innovation
absence of definition of innovation skills and competencies
lack of emphasis on innovation skills and competencies
innovation capacity
2
Legend
Adds to / same direction
Removes from / opposite direction


Search
search for solutions to the innovation gap
perceived innovation gap
conflation of R&D and innovation
lack of definition for innovation
absence of definition of innovation skills and competencies
lack of emphasis on innovation skills and competencies
innovation capacity
innovation education
Legend
Adds to / same direction
Removes from / opposite direction


Search
lack of definition for innovation
absence of definition of innovation skills and competencies
lack of emphasis on innovation skills and competencies
innovation capacity
innovation education
K-12 curricula reform for better innovation education
NLESD Board pressure to reform
Electorate pressure to reform
recognition of innovation skill deficiency
18
opportunities in the knowledge economy
need for innovation skills
generational shifts in work
bias in current curriculo-makers
search for solutions to the innovation gap
conflation of R&D and innovation
perceived innovation gap
R&D activity
innovation learning from outside of the public education system
accessible and practical models for innovation education
other calls for reform
oil export dependency
absence of innovation-trained educators
innovation education programming at Memorial University
innovation education programming at College of the North Atlantic
Provincial government pressure to reform
independent actor calls for innovation education reform
austerity limiting new program growth/development
economic shock caused by oil price drop
low price of oil
budget
Legend
Adds to / same direction
Removes from / opposite direction

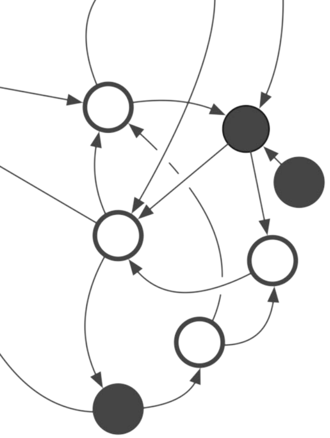


Applying centrality and structural analysis to causal loop diagrams

Metric/Method	Detail	Dynamics models	In Causal Loop Diagrams?
Level partition	Which variables are dependent on which?	Hierarchy of causal structure (Oliva, 2004)	Elements at the “bottom” of the hierarchy are uncontrollable within the system; elements at the top are highly dependent on the rest of the system
Cycle partition	Which other variables share the same predecessors or successors?	Illustrates cycle set “dominance” → sub-cycles sets must be understood before their “parents” (but not *that* useful as most elements in models sit in the same cycle set; Oliva, 2004)	Sub-cycle set elements dictate the behaviour of supercycles
Shortest Independent Loop Set	A decomposition of the cycle partition showing which loops are included in which	- Illustrates a loop hierarchy - With level partitioning, gives an ordering from simple loops to complex loops - Shows isolated loop structures (Oliva, 2004)	- Simple loops are easier to experiment with than more complex loops - Inner loops will influence the behaviour of their containing loops - Isolated structures are more easily manipulated

MEMORIAL UNIVERSITY

OCAD UNIVERSITY



Discussion

- **Important centrality measures:**
  - **Closeness** might be used to find key indicators of success (recall rule 4 of Rittel & Webber, 1973), especially in combination with structural analysis
  - High **betweenness** elements are bottlenecks
  - **Reach efficiency** indicates elements that are minimally influenced themselves but are potentially powerful sources of impact elsewhere
  - **Eigenvector** centrality indicates high-influence elements in general
    - (are these *the* leverage points of the system?)
- **Structural analysis is potentially powerful**
  - Especially in combination with centrality measures

Limitations

- **Does this go beyond the ease-of-use of systems thinking techniques?**
- **What is the “unit” of change?**
  – SNA metrics were developed to model the flow of information... What flows in a systems map?
- **Need for normalization**
  – What is the role of delay? Same/opposite connections?
- **Interpretation is (still) important**

MEMORIAL UNIVERSITY

OCAD UNIVERSITY

Future research

- **Ontological guidelines for mapping and normalization**
- **Guidelines for interpretation and use**
- **Explore additional metrics**
  - Compare with different types of network flows (e.g., Borgatti, 2005)
  - Community detection (e.g., Xie, Szymanski, & Liu, 2011)
  - Automated identification of archetype patterns (e.g., Schoenenberger, Schmid, & Schwaninger, 2015)
- **Weighted metrics + algorithms to implement them**
  - E.g., reach efficiency weighted by eigenvector value
- **Further testing of validity/utility**
- **The need for clear case studies with which to experiment**
- **Systems dynamics vs. systems thinking: from dichotomy to spectrum?**

MEMORIAL UNIVERSITY
OCAD UNIVERSITY

Conclusion

- A novel use of centrality measures and structural analysis is found by importing them into systems thinking
  - These measures are easy to implement in many mapping and diagramming applications
- We may be able to make systems thinking approaches more rigorous without the intractability of systems dynamics

References

Borgatti, S. P. (2005). Centrality and network flow. *Social Networks*, *27*(1), 55–71. https://doi.org/10.1016/j.socnet.2004.11.008

Checkland, P. (1985). From Optimizing to Learning: A Development of Systems Thinking for the 1990s. *The Journal of the Operational Research Society*, *36*(9), 757–767. https://doi.org/10.2307/2582164

Forrester, J. W. (1994). System dynamics, systems thinking, and soft OR. *System Dynamics Review*, *10*(2–3), 245–256. Retrieved from http://onlinelibrary.wiley.com/doi/10.1002/sdr.4260100211/abstract

Freeman, L. C. (1977). A Set of Measures of Centrality Based on Betweenness. *Sociometry*, *40*(1), 35–41. https://doi.org/10.2307/3033543

Freeman, L. C. (1979). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239.

Jones, P. H. (2014). Systemic Design Principles for Complex Social Systems. In G. S. Metcalf (Ed.), *Social Systems and Design* (pp. 91–128). Springer Japan. https://doi.org/10.1007/978-4-431-54478-4_4

Lukyanenko, R., & Parsons, J. (2012). Conceptual modeling principles for crowdsourcing (pp. 3–6). ACM. https://doi.org/10.1145/2390034.2390038

Meadows, D. (1997). Leverage Points: Places to Intervene in a System. Retrieved November 29, 2015, from http://www.donellameadows.org/wp-content/userfiles/Leverage_Points.pdf

Newman, M. (2010). *Networks: An Introduction*. Oxford, New York: Oxford University Press.

Oliva, R. (2004). Model structure analysis through graph theory: partition heuristics and feedback structure decomposition. *System Dynamics Review (Wiley)*, *20*(4), 313–336. https://doi.org/10.1002/sdr.298

Ozbekhan, H. (1970). *The predicament of mankind: A quest for structured responses to growing world-wide complexities and uncertainties* (Original Proposal to the Club of Rome). Geneva, Switzerland: The Club of Rome. Retrieved from http://quergeist.net/Christakis/predicament.pdf

Rittel, H. W., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, *4*(2), 155–169. Retrieved from http://link.springer.com/article/10.1007/BF01405730

Šćepanović, S. (2018). *Data science for sociotechnical systems - from computational sociolinguistics to the smart grid*. Aalto University. Retrieved from https://aaltodoc.aalto.fi:443/handle/123456789/30187

Schoenenberger, L., Schmid, A., & Schwaninger, M. (2015). Towards the algorithmic detection of archetypal structures in system dynamics. *System Dynamics Review (Wiley)*, *31*(1/2), 66–85. https://doi.org/10.1002/sdr.1526

Stroh, D. P. (2015). *Systems Thinking For Social Change: A Practical Guide to Solving Complex Problems, Avoiding Unintended Consequences, and Achieving Lasting Results*. Chelsea Green Publishing.

Xie, J., Szymanski, B. K., & Liu, X. (2011). SLPA: Uncovering Overlapping Communities in Social Networks via A Speaker-listener Interaction Dynamic Process. *ArXiv:1109.5720 [Physics]*. Retrieved from http://arxiv.org/abs/1109.5720

MEMORIAL UNIVERSITY

OCAD UNIVERSITY