Introduction

The Core Public Health Functions Research Initiative (CPHFRI) has identified a serious gap in knowledge concerning how to apply ‘complex adaptive systems’ (CAS) concepts to help guide policy planning, implementation and evaluation for public health interventions. Public health interventions are socio-political and socio-technical interventions in social systems and are aimed at improving both health and health equity toward a more socially just society. We feel that working from a systems perspective is one way to improve social justice and reduce health inequities. There is a need to critically assess and integrate CAS concepts into innovative public health strategies as a high priority but the way to accomplish these goals remains elusive and challenging. This resource list is a starting point to work toward these goals. It has developed from a Canadian Institutes of Health funded metanarrative review of systems thinking in public health. The purpose of the metanarrative review was to map and synthesize existing conceptual and disciplinary approaches to CAS in order to critically assess their potential usefulness and feasibility for guiding the planning, implementation and evaluation of population health interventions. This document is a compilation of approaches to CAS.

The CPHFRI team members are interested in what research methods and approaches have been used in complexity science studies, particularly evaluations of social and/or public health interventions, and to start to identify the strengths and limitations of various research methods and approaches to the application of systems thinking. Secondly, we want to provide practical guidelines, methods, and tools that may be used for applying complexity science concepts to the development and analysis of public health interventions.

To address these objectives, we conducted a targeted literature search specifically for tools, frameworks and methodologies related to complexity science. The purpose of this search was to identify resources that would have a practical application for our study knowledge-users. This was done through the work of a librarian searching Medline (1946 to February 1, 2012) and EMBASE (1980 to February 1, 2012) to identify methods and tools that are used to apply systems thinking to public health practice. Team members also contributed literature they found as appropriate. This is not meant to be an exhaustive list, but to offer a beginning direction for applying complexity and systems thinking methods, and to highlight methods that apply to public health intervention research.

We reviewed the abstracts and selected what we identified as a method or tool that could be replicated either in applied research or contained explanations of tools to evaluate programs or policy from a complexity or systems perspective. While we attempted to create discrete categories, it is impossible to fully appreciate the needs of the users of this document. From our perspective of a research team that has been reading this literature for the past year, we sorted the resources in three ways:

1. Resources that are easy to apply and learn or ways to introduce systems thinking. This includes frameworks or lenses that may help to guide policy planning, interventions or evaluations of public health interventions.

2. Resources that require a workshop, or consultant guidance. This section includes those resources that may be more complex frameworks or more simple and straightforward research methods that can easily be applied to practice areas with minimal guidance. It is challenging to identify what is purely a
simple or easy resource to use, so this category includes resources that could appear easy for some but more challenging for others.

3. Resources that require expertise. This category of resources includes research methods and approaches that would require extensive knowledge or time and may best be used with an expert or research team. They are considered more involved in time and effort, and require a certain amount of expertise to do well. There may be some resources in this category that only require minimal guidance, depending on the experience and strengths of those involved.

In the following table (Table 1), we identify the methods and approaches to studying or implementing systems thinking according to what can help decision makers manage complexity in their organizations. We developed a short synopsis for each resource. The synopsis for the first two categories includes a description of the resource, how it links to complexity science or systems thinking, and the strengths and limitations according to the particular reviewer or noted in the paper. The third section is merely a description of the research method as an overview to what we have currently identified as more complicated methods to study complex systems. These comments on each resource are simply here to help orient you to possibilities on how to apply CAS concepts to help guide policy planning, implementation and evaluation for public health interventions. The appendix in this document (Table 2) is a list of all the methods or tools we have identified for practical use or for research in this area, and the references of papers that will provide further information on the noted resource.

This is a work in progress as we are continually stumbling upon new and innovative ways to guide the work in population and public health interventions. We welcome feedback on this document and look forward to expanding our tool box as we work toward improved health equity and a more just society.

Please send any comments to cphfri@uvic.ca.
### Table 1 Methods/Approaches Reviewed

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### Resources Easy to Apply

**Places to Intervene in a System**


This is an ordered list of places or points to intervene within a system in order to create effective change.

It is an invitation to think more broadly about the many ways there might be to create system change. Describes places within a system to intervene. The “places to intervene” are described and ordered according to effectiveness.

9. Constants, parameters, numbers

8. Regulating negative feedback loops
7. Driving positive feedback loops
6. Material flows and nodes of material intersection
5. Information flows
4. The rules of the system
3. The distribution of power over the rules of the system
2. The goals of the system
1. The mindset or paradigm out of which the system, its goals, power, structure, rules and culture arises.

Strengths: Helps change the way people think about a system.

Limitations: Each point could probably use more reading to understand where to take it. The placement of each item on the list is very tentative. An item could easily move up or down on the list.

**The Five Elements Guide**

This resource is limited to sustainability and environmental initiatives, but is included because it may be adaptable as an introduction to systems thinking.

Informed by systems thinking, the Five Elements Guide provides a strategic resource for engaging individuals in sustainability activities and societal change. In other words, this resource focuses on individuals and their motivation and capacity for change. The Five Elements Guide was developed by two Swedish authors building on their personal knowledge and experience, as well as a trans-disciplinary literature review. It offers an approach for creating and improving engagement strategies for societal change.

Strengths: The Five Elements Guide offers a simple, detailed and flexible approach for engaging individuals in strategic change related to sustainability. It describes a number of tools and resources for the concepts and notions (i.e. change and systems) related to sustainability and systems thinking, and use case examples.

Limitations: As documented by the authors, the Five Elements Guide could improve from further feedback, development, and testing. Also, the guide is focused primarily on the “individual” system, rather than the system as a whole.

**The Generic Five Level Framework (5LF)**

This is a basic resource that may be adapted to public health and provides an introduction to systems thinking.
The Five Level Framework (5LF) is a planning model informed by systems thinking, and can be applied to any complex system with a particular desired outcome. This thesis explores how urban agriculture can be supported to help move cities towards sustainability. The five levels consist of system, success, strategic, action, and tools. According to the authors, 5LF is applicable in all planning contexts, whether local, regional or national.

Strengths: 5LF provides a basic model for planning. 5LF applied to urban agriculture is the foundation of the framework for sustainable strategic development used in this same study.

Limitations: 5LF is quite basic.

Health in Cities Framework

This resource offers a framework for intervening in the health of urban city residents.

The Health in Cities framework builds from the healthy cities movement. The framework aims to create effective health interventions for people living within urban environments. The framework recognizes that there are multiple and sometimes competing issues within an urban environment. Each city is unique and comprised of a variety of groups. The Health in Cities framework conceptualizes cities and health as complex adaptive systems (CAS), and consists of 7 components for developing effective health interventions: 1) gather local information; 2) respect history; 3) consider interaction; 4) promote variation; 5) conduct selection; 6) fine tune process; and 7) encourage self-organization.

Strengths: Builds on the traditional urban health and healthy city movements. The framework recognizes the strengths or assets of a city, not merely the issues or needs.

Limitations: This resource offers a nice framework, but may be limited to urban health settings.

Intervention Level Framework

This is a simple and concise framework useful for helping stakeholders understand systems and create system-wide change.

The authors adapted Meadow’s “12 places to intervene” framework into a 5 level framework (paradigm, goals, system structure, feedback and delays, and structural elements). The Intervention Level Framework was used to sort qualitative data related to food systems. In other words, the authors used the food system as an example to apply the framework by looking at the five levels: paradigm, goals, system structure, feedback and delays, and structural elements. According to the authors, “With the Intervention Level Framework, stakeholders can develop a better understanding of how coherent actions among and between subsystems, together with enhanced self-regulating feedback loops and interconnections between subsystems, can create system-wide change” (p. 476).
Strengths: A simple and concise framework.
Limitations: May be too simplistic.

**LENSES (Living Environments in Natural, Social, and Economic Systems)**


This is a whole-systems framework that promotes healthy, natural, social and economic system development.

LENSES works from the understanding that positive and improved development requires a whole-systems approach to design that generates relationships among ecological, economic, and social issues. As such, LENSES attempts to shift the focus from individual elements within a system, to the patterns, connection and relationships between elements in a system. The LENSES framework is appropriate for small and large projects across all programme areas. The aim of LENSES is to inspire and create development and change that supports the creation of healthy, natural, social and economic systems.

Strengths: According to the authors, LENSES framework represents the best information related to sustainability. LENSES framework is user-friendly, and adaptable to a variety of contexts. Also, LENSES encourages people to consider concepts and elements often missing in other resources (i.e. inclusivity, financial sourcing, cultural resources, regional context, education, shared authority and governance, and on-going prosperity).

Limitations: LENSES is quite new, and is not well tested.

**Liberating Structures**


This is a compilation of 31+ methods designed to stimulate creativity and innovation.

Inspired by complexity science, and developed from the Plexus Institute, LS consists of over 31 methods to inspire people towards innovation. LS has successfully been used in the pharmaceutical industry, who it was developed for, as well as hospitals, nongovernmental organizations (NGOs), government agencies and academic institutions. LS aim to change the pattern of interactions within a group, in order to stimulate creativity and innovation. People from all levels are encouraged to use their voice, participate and contribute.

Strengths: LS is an easy approach that requires little time investment. According to the authors, one or two experiences with LS are enough practice for anyone to begin experimenting with the resources. LS support practice that is congruent with complexity science, but does not require that people have experience related to complexity theory/science.

Limitations: None identified.
**Behaviour-over-time Graphs**

Systems thinking tools serve to describe and understand Complex Adaptive Systems (CAS). A CAS is a dynamic network of many heterogeneous agents (e.g. individuals, groups, organizations) that interact freely and in ways that are nonlinear (inputs not necessarily proportional to outputs) and not necessarily predictable (Anderson, Crabtree, McDaniel, & Steele, 2005; McDaniel, 1999). Systems thinking tools, such as behaviour-over-time graphs, help visualize the overall system structures and relationships. They allow stakeholders to understand the many different components and their interrelations, thereby making it easier to identify appropriate points of intervention.

Behavior-over-time graphs are similar to other basic graphs in that they have horizontal and vertical axes. These graphs are used to plot a behavior of interest (vertical axis) over time (horizontal axis) so that the behavior can be examined from a systems thinking perspective.

Strengths: Relatively simple and help to identify patterns of changes over time. It has been used in public health for years.

Limitations: You need to have the data in a constant form over time.

**Systems-in-Transition Paradigm for Healthy Communities**

This is a conceptual diagram to organize community into five functional interdependent subsystems of 1) production; 2) social control; 3) social participation; 4) socialization; and 5) mutual support, and describes the process of community development and stress. It is intended to aid in holistic community assessment.

The paradigm is built on general systems theory to help practitioners think about the way a community is organized.

Strengths: Easy to follow diagrams to consider the impact of stress, adaptation and change.

Limitations: Not well used for seeing how well this has been applied.

**Resources that Require Guidance**

**Casual Loop Diagrams (CLD)**
CLD provide a new take on the traditional perception of cause and effect in organizational relationships. They break with the idea that decisions and their outcomes constitute linear relationships by showing that interrelated variables create feed-back loops that ultimately complicate the outcomes of decisions and effects of interventions. The diagram provides a visual representation of the most salient variables in a system or an intervention and how these variables are related to one another. The diagram includes descriptions of the various connections between the variables and how these might impact one another and cause change. This tool may be used as a starting point for model conceptualization of a problem or an intervention to help portray the larger system that said problem or intervention is part of, and identify specific relationships of interest.

Strengths: A benefit to using CLD is that it quickly and easily helps people new to systems thinking grasp the basic concepts of this kind of analysis and understand how to implement systems thinking tools. Causal loop diagrams may provide an initial basis for simulation modeling in which a variety of futures can be explored and leverage points can be more accurately identified.

Limitations: The actual diagram may lack some relevant variables, and errors are present in the connection/loop structure. Adequate training is necessary to properly use and benefit from this tool.

**Concept Mapping**


While Systems thinking is a general conceptual orientation concerned with the idea of interrelations between multiple agents in a complex structure, systems modelling is a methodological tradition concerned with operationalizing systems thinking by using models and simulations. Concept mapping is one such model. It enables users to develop a shared conceptual framework that can be used in a variety of policy contexts to identify or encourage complexity. System effects are thereby made transparent and power disparities are highlighted, by using a systematic and formalized research tool.

Concept mapping is a web-based model that organizes statements generated by a group of people, concerned with a particular topic, into piles of synthesized statements. The piles are statistically analyzed and configured into a map that shows clusters of statements, with the more similar ones located closer to each other. When users look at the map and plan or evaluate interventions based on them, they engage in a continuous process where planning, action and evaluation intertwine and continuously adapt to one another.

Strengths: Concept mapping is a model that is very accessible for diverse groups of people and therefore a gateway to incorporate complexity into public health interventions. The method is inductive and allows shared meaning to emerge. As it is based on a simple set of rules (operations) that generate a visual representation of complex patterns and results, it can help a diverse group of users engage with multiple ideas for planning, executing, and evaluating interventions simultaneously as it provides a framework that enable users to align action with a broader organizational or systems vision.

Limitations: The web-based model is expensive and the cost is applied for each use.
Inter-Professional Education Intervention

Inter-Professional Education (IPE) is an intervention tool and evaluation tool. The intervention involved a number of key developments including a staff-training programme, generic e-learning materials, and a student team-working skills intervention. Provided this way it requires a trainer and a group setting. The intervention is therefore best used with a group of students, a professional team, an office, or other groups of health care providers that work together across disciplines.

This paper refers to the authors’ 2004 paper on Complexity and Inter-Professional Education where the theory is discussed. It references Campbell’s guide to evaluation of health promotion interventions that are complex, pragmatic and context dependent. The learning process of IPE is in line with systems thinking: it enables competence and capability to adapt to change. Complexity theory, with its focus on connectivity, diversity, self-organization, and emergence, can provide IPE with a coherent theoretical foundation, freeing it from the constraints of a traditional linear framework, enabling it to be better understood, questioned and challenged as a new paradigm of learning. The pilot project found it promoted theoretical learning about team working, enabled students to learn from and with each other, and raised awareness about collaborative practice.

Strengths: In a pilot project it was used to enable students from different professional groups to work together, learn from each other, and improve the effectiveness of team work to impact health care delivery positively.

Limitations: In the pilot project the intervention was targeted at first year students. This group of learners might be more receptive to it than older students or already established researchers/practitioners. Furthermore, the intervention requires time as there is a learning process. It might be beneficial to try to implement the intervention in “real life” settings rather than in educational settings, to maximize its effect and speed up the learning curve.

Positive Deviance (PD)

Positive Deviance (PD) is a concept that was operationalized by American academics in the 1990’s as a tool to create social change. It is based on the observation that in every community there are individuals or groups of individuals (called Positive Deviants), where uncommon but successful behaviors or strategies enable them to find better solutions to certain problems than other community members.

A PD solution to a problem is found following the basic guideline disseminated by the Positive Deviance Initiative, a global organization with an online presence. There are four steps to the process: 1) define the problem, 2) determine the presence of PD individuals or groups in the community, 3) discover uncommon but successful behaviours or strategies through inquiry and observation, and 4) design a solution based in activities that allow other community members to practice the discovered behaviours or strategies.
Strengths: PD is an asset-based approach to solving problems which taps into the unrealized and unused resources that a community may possess by amplifying such uncommon behaviours and strategies discovered by otherwise unsuccessful members of the community. It is used to solve complex problems on a global scale (but from a local vantage point) in diverse sectors, among them public health and education.

Limitations: PD is easy to apply, but requires the participation of an entire community, as well as leadership commitment to address the problem. Also, it is best applied to complex problems that that are social in nature and require behavioural and or social changes, more so than purely technical solutions.

**Program Budgeting & Marginal Analysis (PBMA)**


PBMA provides an economic framework and assists with priority setting in healthcare systems. There are 7 stages: defining the aim and scope; developing a program budget; creating an advisory group; developing decision making criteria; identifying options for investment and disinvestment; evaluating options; and validating results and the reallocation of resources.

Strengths: Provides transparency of spending, involves high level consultation, realistic approach to planning; uses multiple sources of information.

Limitations: Difficult to prioritise over different sectors; lack mechanism to implementation recommendations; need to overcome organizational barriers to change. (See Willis et al., 2012 reference for more on strengths and limitations)

**Soft Systems Methodology**


Soft Systems Methodology (SSM) is a process of inquiry that organizes thinking about complex situations so action can be taken to improve a situation. The authors describe a process where a problem is perceived, world views identified and different people are taking action on the problem. Models of the activities are created that open a space for discussion about changes that are both desirable and feasible, to find a version of the situation that is acceptable to different worldviews, and then changes can be implemented, continuing the cycle to work out the challenges. It is considered to be a direct response to real-life experiences.

Strengths: It helps to focus situations where there is strong discontent without clear direction, and helps to make sense of ambiguous situations. It encourages positive attitudes and good communication. Considers clashing worldviews as opportunities for energetic and motivating creativity.

Limitations: Skilled facilitator is needed to encourage respectful negotiation between clashing worldviews.

**Systems Dynamics Modeling**

Systems Dynamics Modelling is a way to map and thereby understand the many forces at play in complex systems. It also recognizes the tendency of such systems to be in a constant state of change, and thereby delay, defeat or dilute the intended effects of planned interventions. While Systems Dynamics Modelling is not a tool to predict the behaviour of a complex system (a characteristic of which is that it is unpredictable), the modelling can help users ask relevant questions to proposed interventions. More importantly, the modelling enables diverse stakeholders to combine their knowledge and develop dynamic hypotheses and test these against computer simulations that play out multiple possible scenarios of change to an intervention.

A good place to start for learning and using Systems Dynamics Modelling is Road Maps — a self-study guide. It was developed by the System Dynamics in Education Project (SDEP) at MIT under the direction of Professor Jay Forrester. Organized as a series of chapters, ten chapters of Road Maps are available for download. Road Maps teach the reader how to identify different kinds of systems all around us and how to model these systems. Road Maps can be a resource for both beginners and advanced System Dynamics modellers. It requires no previous System Dynamics knowledge and only basic math skills. However, some time and practice is needed to go through the program.

Strengths: The first step in systems dynamics modelling is causal loop diagrams providing a map of the system and interactions of the parts. Helps to highlight workings of a system and the consequences of decisions.

Limitations: You need good data to put into the equations. Special software is required

**Viable Systems Model**


The Viable Systems Model comes out of organizational science, and emphasises communication among five functions of an organization: operations or the provision of needed services; effective coordination; support and control for things like resources, training and information; intelligence or the forecasting for needs, opportunities and threats; and policy making for long term goals and objectives. The success of an organization is that it is adaptable.

Strengths: Appears to be an easy, straight forward model to follow, with a long track record.

Limitations: None noted.
Research Methods
In this section we will only give a brief overview because this primarily relates to research methods requiring more in-depth training.

Action Research from a Systems Perspective

This paper is about conceptualizing research as an intervention. Systemic intervention is purposeful action by an agent to create change in relation to reflection on boundaries. Methodology for systemic intervention should be explicit about three things: boundary critique, theoretical and methodological pluralism, and action for improvement.

More traditionally, action research engages the system “insiders”, and when working toward system change, this can be a very powerful research method.

Agent-based Modeling

This method is computational modeling research that uses simple rules and is focused on individuals and the way they interact in a system. It captures emergent occurrences and provides a natural description of the system.

Case study CAS Framework Applied

This paper uses a case study approach to apply a framework for complex adaptive systems. It includes key characteristics of agents, interconnections, self-organization, emergence and co-evolution. The principles focus on the systems history, patterns, dynamics, processes, unexpected events, non-linearity, relationships and interdependencies.

Community Operational Research

Known as Community OR, this is more in the realm of community development and not entirely seen as a part of systems thinking, but with overlapping interest and ideas. This book covers ideas such as the synergy between boundary critique, which is a way to conceptualize marginalisation of people and issues in complex systems, and methodological pluralism, which engages multiple methods from different paradigms. There is a chapter on participatory appraisal of needs and development of action (PANDA) and the use of metaphors and case studies. The final chapter in this book presents Adaptive Methodology for
Ecosystems Sustainability and Health (AMESH). This is rooted in theories of complex adaptive systems, has a set of ‘guiding principles’ and ‘guiding questions’ for the methodological processes.

**Computational Modeling**

This paper describes computational modeling as a tool for implementing evidence driven policy design. Similar to agent-based modeling or simulation modeling, computational modeling helps the study and design of solutions by simulating various environments, interventions, and the processes where certain outcomes emerge from policy maker’s decisions. It allows the observation of both the intended and unintended consequences of policy alternatives. It also facilitates communication and consensus-building among policy makers and diverse stakeholders.

**Discrete Event Simulation (DES)**

This paper describes the use of computation modelling, agent based modelling and DES. DES utilizes mathematical formulas (differential equations) to model a system as it evolves over time by a representation in which state variables change instantaneously at separate points in time. According to the authors, the process instills confidence that the team is on the right track and potential problems are identified early. The software applications require expert knowledge to use in real life situations. Software application does not change the process of decision making.

**Grounded Neural Networking using a Self-organizing Map**

The self-organizing map can analyze complex quantitative data to develop a grounded theory. It is a post-positivistic, nonlinear clustering technique that can comb through large, complex numerical databases to find nonobvious patterns and relationships between conceptual indicators derived from various forms of data: quantitative, graphic, narrative, and audio. It emerges from the artificial intelligence literature with origins from the field of complexity theory.

**Mathematical Modeling**

In this paper the authors explore synergies between modeling of ARV-resistant HIV and pandemic influenza. They claim that combining techniques of operations research with dynamic modeling would enhance the contribution of mathematical modeling to the prevention and control of infectious diseases.
Organizational Network Analysis (ONA)

In this paper the authors describe an ONA as a quantitative, empirical method for modeling organizations as interlocking networks of people, tasks, resources and knowledge to aid human cognition in understanding the organization as a complex socio-technical system. It can potentially be used to guide process planning such as information system improvements to increase performance. It presents an opportunity for informaticians and practitioners to build collaborative knowledge to improve public health systems. The authors identify it as having value for public health managers, but needs refinement for the public health domain.

Reality Mining

Reality mining tracks human behaviour patterns through their use of electronic devices. Computational modeling on the basis of this data can be used to provide a time sensitive picture of interactions over time. Advanced mobile phones have accelerometers that can measure body movements and geolocation hardware such as GPS. It also can aid in automatically mapping social networks.

Situational Analysis

Situational analysis is an approach to research using a grounded theorizing methodology to frame basic social processes, and by representing complexity through mapmaking. The methodology for situational analysis is substantive theorizing and story-telling through the use of maps with a goal of critical analysis to produce a possible ‘truth,’ or underlying structure or mechanism. Situational analysis provides a means to specify and map all the important human and nonhuman elements of a situation, emphasizing relationships, positions, social worlds and discursive positions.

Social Network Analysis

Social Network Analysis (SNA) is a method used to shed light on complex patterns of interactions between actors. Developed out of social anthropology, SNA allows for the description of social structures as networks and helps to interpret the behaviour of actors in light of their position within the social structure.

Structural Leverage Analysis

Structural leverage analysis and synthesis examine how well multiple actors align their goals with organizational resources. The analysis entails examining multiple, interrelated feedback loops in a strategic
situation or system, composed of the sub-systems previously examined for dynamic leverage. SL analysis and synthesis bring system thinking tools to strategic planning in order to help managers capture, understand, analyze, design, and communicate the complexity inherent to the dynamic systems in which we all live and work.
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### Systems-in-transition paradigm for healthy communities


### Viable Systems Model

