Introduction to Systems Thinking
This booklet provides an introduction into systems thinking and was developed to document the work of students exploring the intersection of systems, research and design at Carnegie Mellon University’s School of Design.

What is presented here is an overview of a semester’s worth of work and captures everything from key terms and concepts, to a historical overview of significant systems thinkers, includes individual and group student projects and ends with complexity mapping wicked problems in the Pittsburgh region.

Thanks to all the students that participated and who eagerly engaged in course material, to all the guest speakers who helped facilitate class discussions, the people who contributed to shaping this course and a special thanks to the team of design students who put this resource together – you went above and beyond and this booklet is a testament to your aspirations.

Francis Carter & Sofía Bosch Gómez
Systems are everywhere in our lives. But what exactly is a system? This chapter provides a definition of a system and a general overview of the history of systems thinking.
In the current century, as the distinctions between nature, culture, and the man-made become increasingly entangled and inseparable, we can no longer talk about design outside of its role in determining the shape and form of ecological, cultural, and socio-technical systems, models of aspects of the world that can guide intentional change.

The Design Studies core curriculum was designed to be the backbone of a modern curriculum that would empower students at Carnegie Mellon University’s School of Design with new mindsets, knowledge, approaches and tools that they would need to tackle the unique complexities and challenges of 21st century design problems. As part of the School of Design’s prerogative to train a new generation of designers who could design for systems-level change and societal transitions over long time scales (transition design), Systems was designed as the core course that would expose Freshmen students to observing, analyzing, and then carefully planning and intervening in systems.

The Systems course leads students, in a roughly chronological fashion, through a range of different approaches and methods to analyzing and describing complex human phenomenon, from cybernetics to wicked problems to living systems theory, teaches them specific systems thinking techniques and terminologies for systems analysis, and making changes that they can assess for their impacts, to those phenomena. The students learn to employ concepts like feedback loops, frames, leverage points etc., in the service of understanding these phenomenon holistically and a better sense of where and how to design interventions, whether artifacts, services, environments, platforms or policies, more effectively, and be in a better position to take responsibility for the consequences of their proposals.

This course has, over the course of four years, undergone substantial revisions and changes. Initially designed as a seminar, it has since evolved, over successive iterations, into a course where freshmen students spend a significant portion of their time on both in-class exercises and longer projects. The shorter exercises give them a sense of how to translate the theory that they've been exposed to in lectures into workable method, while the projects introduce them, in a clear progression of assignments that build in complexity, rigor, scale, and stakes, from an individual project where students have to represent themselves as a system, to their final group project, where they pick a large, messy problem that the city of Pittsburgh is facing and have to conduct field research to map and study the problem, identifying points where solutions can be furnished, and present the viability of their chosen solutions.

This booklet acts as a documentation and guide to the course and what it has developed into over four years of refinement. Many systems, including this booklet, as a graphical and textual system that sheds light on the content and outcomes of this course, are goal-oriented - the purpose of this document is to shed some light on how we have envisioned and materialized our intent to furnish students with the basics of systems thinking and complexity theory in order to help shape and mold them into designers that can think and make beyond artifacts. We hope that this document will inspire and lead educators elsewhere to incorporate systems thinking into their own curricula and courses.

Ahmed Ansari
WHAT IS A SYSTEM?

01 A representation of a set comprised of interrelated and interdependent parts that form a unified whole and continually interact with each other.

02 Usually has a goal and involves actor(s) and intent(s).

03 A combination of tangible and intangible components.

04 Has open and closed perspectives. An open system interacts with the outside environment, taking input from and releasing output to the environment while maintaining its boundaries. A closed system does not interact with the outside environment; its interactions occur within the boundaries.

05 Can be interpreted through multiple scales — immediate, intermediate, and broad. An example of an immediate system would be the components that form an observer’s identity. An intermediate system is a local system that can be found in a local community or a city. A broad system can be a system that is beyond immediate and intermediate systems, such as a state-wide, national, or world-wide system.
Can be viewed through different lenses; such as social, political, and psychological; that provide framework to view a system. Depending on the chosen lens, the observer can interpret the system differently.

Composed of two types of feedback loops – positive and negative. While positive feedback loops increase a tendency in a system, negative feedback loops curb and stabilize those tendencies. For example, birth is a positive feedback loop to Pittsburgh’s population because the more people are born, the more people there are in the future to give birth. However, death acts as a negative feedback loop and stabilizes the population.

Constrained by the boundaries delimited by the observer; subjective representation of reality; critical to set boundaries when discussing a system with others so everyone can be on the same page; entire world cannot be bounded: only parts of the world can be bounded.

Can be used as an analytical or a speculative tool to analyze future processes.
HISTORY OF SYSTEMS THINKING

Kurt Koffka
“The whole is other than the sum of the parts... This is not a principle of addition”
Discovered the fundamental quality of a system: different elements come together and form a unique result.

Stephen Pepper
Context is necessary to understand the entire system.
Example: lemonade
sugar + lemon + water; the ingredients have different taste but the flavor becomes unique to lemonade when the ingredients are mixed.

1923
Gestalt Theory: Holism

1942
Contextualism
Herbert A. Simon
Theorized that organization is a system of coordinated actions among individuals and groups whose preferences, information, interests, and/or knowledge differ
Speculated that humans are simple but external influences make humans complicated

Ludwig von Bertalanffy
Pioneered the general fundamentals of a system; noted the difference of open and closed systems; applied systems thinking to social science topics (i.e. growth, decay, and evolution).

Norbert Wiener, W. Ross Ashby
Cybernetics = a scientific study of the communication in humans, animals, and machines
Theorized positive and negative feedback loops; studied and analyzed the relationship among co-ordination, regulation, and control among cybernetic systems

1946
1948
Realized that a system is in a cyclical organization, where one sub-system causes another sub-system.

Specifies the research into the observer’s attention to a specific part of a system, studying boundaries and the way people perceive parts of a system.

Margaret Mead, Heinz von Foerster

Russell Ackoff

“Systems is more than the sum of its parts”

Believed that once elements combine to form a system, the effect is greater than just the parts combined.

1957

Operations Research

2nd order of Cybernetics

1968
To understand the complexity of a system we will analyze it first from the most immediate and personal context – the self as a system. Then, we will apply these concepts to larger scales such as societal and global.
Firstly, to understand the complexity of a system, one needs to understand how it works at its lowest level or in one’s immediate context. For most, this immediate context would be the individual as a system. We can break this down to our consumption, health, how we live, work, and more. A system cannot function without its connection to aspects inside and outside of its realm. Therefore, to better understand the individual system, we look at the basic social structure, a household to further understand ourselves as a system.

While the complexity of the family is of a high order, the scale is manageable. It is one we are comfortable with. We call it the “human scale”. In the family setting, we immediately get feedback about whether our actions are producing the results we intend.

- Elise Boulding
Households as systems whether represented by something tangible or intangible can be categorized into:

01 Population, resources, culture, technology, determined by boundaries, and environment

02 Form of political organization: matriarchy, patriarchy, egalitarian

03 Economic organization: high tech industrial or subsistence economy

04 Division of labor: high differentiation between sexes and ages or low differentiation

05 Division of resources: equal share or unequal

06 We can understand more about the household as a system by looking into the tangible and intangible influences and artifacts in our everyday life. We used the Cabinet of Wonders as to understand systems at a micro view.

One reason the complexity is unrecordable is that each member of a household is growing and changing every minute.

- Elise Boulding
Yoshi Torralva | This project was able to translate multiple layers of analysis into the ultimate contemporary cabinet of wonders: a museum.
Langston Wells | He interpreted the project from a literary perspective, where he interprets himself as a system through the books he reads and what can be found on his bookshelf.
Andrea Benatar | This project had a multimedia approach where the cabinets gave the viewer an understanding of the nested cultural background of the designer. Each cabinet showcased a different city, urban environments that impacted her.
Larger scale systems often form around one or more human values, present at multiple levels, connecting groups of individuals together within multiple community systems. This chapter covers additional aspects which support communities, including tool systems, values & goals, and stakeholder structure.
**TOOL SYSTEMS**

**Affordances:** What does the tool allow you to do? How should it be used? What signifiers (visual cues) are prevalent in tools?

-- Passive User vs Active User / Environmental User vs Direct User

-- **Ready-to-Hand** vs **Present-at-Hand**

Unconsciously able to operate the tool vs requires conscious attention to utilize the tool

Tools can shift from one state to the other either through being fixed or breaking down.

Context matters in relation to the tool, affects usage of the tool as well as perceived affordances of the tool.
Communities act as larger, more complex systems of the individualistic systems explored in the previous chapter, with smaller systems (people) interacting with one another and the community itself, all within the community system.

Community Systems can form around a number of larger aspects, including but not limited to: Place, Culture, Interest, Resistance & Practice

Community Systems more frequently form as organizations, including: Community Groups, Nonprofits, For-profits, Institutions and Faith-Based Communities
Always consider mapping the following elements of a system --

**Stakeholder:** Either an individual, group or organization who is impacted by the outcome of a project, organization or community. They have an interest in the success of the project, organization or community. Either an Internal or External Stakeholder, depending on their location/involvement relative to the examined system and the defined bounds of the system.

**Community Values & Goals:** Scaling values to Macro and Micro

Inputs & Outputs of a system

**Edward Tufte Principles:**

**Data-Ink Ratio:** Ink used to describe data/Ink for everything else

Focus on substance being communicated through visuals rather than just the visuals design itself (secondary importance)
NewPeople is a newspaper published as part of the Thomas Merton Center in Pittsburgh. As a social justice newspaper, it focuses on writing stories about groups marginalized and ignored by mainstream news. This system map explores the NewPeople newspaper by placing it in context of its values, the people involved, its impact, and the interactions between these layers.
UPMC URGENT CARE

Why we are mapping UPMC

Human beings live within places, move between places, and exchange ideas and products among places. Places and their unique characteristics are a critical part of society because they provide the ability for people to lead their lifestyles in the most beneficial and comfortable way they can. The idea of being surrounded by these constant, structured places can provide individuals with a sense of community and stability.

Hospitals are one of those indispensable communities that everyone interacts with. They are established as controlled environments that serve as a constant, reliable infrastructure.

Because of the importance that hospitals provide a community, mapping the processes, people, and groups within UPMC allows people to view how the flow of power, money, people, goods, and services, and conversation operate within a large hospital structure. Being able to visually express these exchanges of work allows for the simple interpretation of complexities and aids in the reform of hospital structures in an easy and effortless manner.

Purpose of UPMC

UPMC stimulates an environment where staff promote the care & research that help patients & the general public eliminate health problems.

UPMC Services

Immediate Care
Colds, flu, stitches, fractures

Preventative Care
Flu shots, Check-ups

Physicals
For sports, work, driver’s licenses

Prescription Filling
For most medicines

UPMC URGENT CARE Flowchart:

1. Get appointment + request treatment
2. Connect patient with nurse
3. Receive overview of symptoms
4. Deliver patient’s medical info
5. Diagnose patient
6. Check out from hospital

Register patient into system
Receive info on patient
Express symptoms
Receive patient’s medical info
Receive treatment plan
Check patient out of system + process payment
Yogini Borgaonkar, Sammie Kim, Janet Peng, Mary Safy | They created interesting scalar shifts while mapping a massive institution like UPMC. They approach was nuanced, following the process of a patient admitted into the ER and moving towards mapping a full ecology of the institution, including time variables.
At the center of manufacturers, consumers, and Avalon Exchange lies a common goal: representing the fashion identity of the community. It adheres well with Avalon's mission of reflecting the community's fashion by providing affordable, locally exchanged goods for the public.

Start of the scarfs journey

Here, members of the public thrilling community enter the cycle. Typically, they will hear about Avalon Exchange through friends that have made purchases.

As the scarf finds its way to owner, it progresses through a product lifecycle before the new owner decides to sell it yet again.

Point of Purchase:
Scarf sold from
Retailer to Consumer

money

Fashion
A shared sense of fashion is what ranges Manufacturers with Consumers

Community Fashion

money

money

Community
The intersection between Avalon Exchange and local consumers represents the Pittsburgh community

money

Ownership

money

managers

Managers
This team approached complexity mapping in quite a designerly way by following a scarf’s journey from a user to the next, with the store as intermediary.
Wicked problems describe issues that are complex, everchanging, interconnected, and cannot be solved through step-by-step interventions. They can be analyzed like systems, which we practiced by mess mapping wicked problems in Pittsburgh. Donella Meadows’s leverage points provide a framework for thinking about how to effectively intervene in a wicked problem.
WHAT IS A PROBLEM?
A problem consists of:

01 **Framing**: How a problem is framed depends on the individual framing the problem. For instance, a humanities professor will frame a problem differently than an engineer.

02 **Cause & effect**: the person framing it must articulate the cause.

03 **Needs “intervening”**: intervening is defined as moving from a current state to a more preferred state.
WHAT IS A TAME PROBLEM VERSUS A WICKED PROBLEM?

A TAME PROBLEM CONSISTS OF:

01 Clear Cause + Effect
   Light bulb is not turning on
   Why? The bulb is broken

02 Step-by-step Intervention
   Unscrew the light bulb
   Buy a new light bulb
   Screw it in place

A wicked problem is not as clear cut as a tame problem and can be treated like a system.

A WICKED PROBLEM CONSISTS OF:

01 Infinite causes and effects depending on how you frame the problem
   Housing segregation (cause) can cause lack of accessibility to education for minority students (effect), but housing segregation (effect) can be the cause of racial steering (cause)

02 Different ways of framing

03 No step by step intervention
WHAT IS A WICKED PROBLEM?

10 Characteristics of a Wicked Problem (Rittel and Webber):

01 There is no single way to define a wicked problem. Thus, interdisciplinary teams are ideal to intervene in wicked problems.

02 Every wicked problem is a symptom of another problem, so there is no start or stop to the problem.

03 You cannot solve a “wicked problem”; you can only intervene to better the situation.

04 Interventions cannot be true or false, only good or bad.
   
   Good is measured by the positive effects outweighing the negative effects.
   
   “Good” and “bad” depends on the stakeholders and their goals.

05 Once you intervene in a wicked problem, the whole system changes.

06 There are an infinite number of ways to frame and intervene in a wicked problem.

07 Every wicked problem is unique, so interventions for one situation may not be applicable work for other wicked problems.

08 There is no immediate and ultimate test to evaluate how successful an intervention is.

09 The framing of a wicked problem suggests the nature of the intervention.

10 The planner is responsible for the consequences of their intervention.
Mess maps attempt to make sense of a wicked problem by depicting its problems, stakeholders, causes, influences, events, and relevant data. To communicate this information, mess maps often involve pictures, icons, metaphors, quotes, illustrations, objects, and data.

All maps, including mess maps, have their limitations because maps are socially constructed and therefore subjective. For instance, the Mercator map used to represent Earth’s geography downsizes South America and Africa and upscales countries in the Northern Hemisphere.
HOW TO DO WE INTERVENE IN A WICKED PROBLEM?

12 LEVERAGE POINTS (according to Donella Meadows)

These leverage points are ranked in order of effectiveness as well as increasing difficulty to intervene in.

12 Constants, parameters, numbers: involve numbers
11 Buffers: making your stock stable by increasing its size and decreasing its flow
10 Material: redesigning the physical system
09 Delays: length of delays relative to the rate of the system changes
08 Negative feedback loops: adjusting the strength of negative feedback loops relative to the impacts they are trying to correct against
07 Positive Feedback Loops: reducing the gain of a positive feedback loop. When a positive feedback loop is uncontrolled, the system will ultimately collapse.
06 Information: who does and who does not have access to information
05 Rules: incentives, punishments, and constraints of a system
04 Change & self organize: the ability to evolve a system by creating new structures
03 Goals: changing the goals of the system
02 Paradigms: changing shared public perceptions
01 Transcend Paradigms: realizing that no paradigm is completely true
Waste Management

This poster explores the wicked problem of Pittsburgh's waste management system. It examines how various types of waste get transported to and from different locations and the complex issues that arise during the processes. Many networks within the waste management system have a notable impact on the environment, people, and various aspects of human society.
Opioid Epidemic in Western Pennsylvania

Mihika Bansal, Yogini Borganonkar, Jina Lee, Evelyn DiSalvo, Annalisa Pao, Jamie Park
Declining Population of Pollinators

Tay Arau, Andrea Benatar, Raymond Pai, Zee Salman, Caroline Song & Yoshi Torralba

The declining population of bees has been a rising problem for several decades now. However, the problem has only gotten worse with the rising rates of urbanization and human expansion in the twenty-first century. In creating this map, we first had to determine the broader, "worse and related problems," from which we could then draw direct and indirect connections to more specific issues. This map has been designed to help illustrate helpful and hurtful stakeholders, which is the most relevant for Western PA or Greater Pittsburgh.
GLOSSARY

Ch. 01: Introduction to Systems

Scale: an abstract interpretation of different sizes—in systems, scales refer to the extent of impact: personal, community, city, state, national, global scales.

Lens: a filter that helps one observe parts of a system

Positive feedback loop: reinforces tendencies of a system by adding elements into it

Negative feedback loop: stabilizes a system by subtracting elements from it

Boundary: a way to limit the way one represents a system—typically bounded through scale

Ch. 02: Self as System

High tech industrial economy: firms, industries and markets in a society that emphasizes the production of modern technology

Subsistence economy: wealth of an economy dependent on the ability of individuals and families providing for themselves

Cabinet of Wonders: a notable collection of objects. Modern terminology would categorize the objects belonging to natural history, geology, ethnography, archaeology, religious or historical relics, works of art, and antiquities.

Ch. 03: Communities

Tool Affordances: The various applications of the tool available to the user

Ready-To-Hand: User able to unconsciously operate the tool

Present-At-Hand: Requires conscious attention from the user to operate the tool

Stakeholder: An individual, group or organization who is impacted by the outcome of a project, organization or community.

Ch. 04: Wicked Problems

Framing: a way to present or understand an issue

Intervention: interfering with an outcome, not necessarily solve a problem

Leverage Points: places within a system where interventions can create a large impact

Stock: quantities that can increase and decrease (e.g. water in a bathtub)

Buffers: big, stabilizing stock

Paradigms: deep, societal belief system
Leverage points (in increasing order of effectiveness):

12. Constants, parameters, numbers: involve numbers

Bathtub Metaphor (described by Donella Meadows): In a bathtub, the constants determine how the faucets turn and let water into the bathtub. Faucets can turn quickly and allow water through with great force, or faucets can only allow a small flow of water because of blockage in the drain.

Real life example: Corporations adjust the wages they pay their workers (one faucet) and the prices of their products (another faucet) to achieve their profit goals (level of water in the bathtub).

Limitations: Intervening through constants does not address the root of the system but acts as a “band-aid solution” to prevent more damage.

11. Buffers: making your stock stable by increasing its size and decreasing its flow

Bathtub Metaphor: A large bathtub with slow in and out flows is more stable than a small bathtub with fast in and out flows.

Real life example: Saving your money without constantly withdrawing allows for a more stable lifestyle.

Limitations: Buffers are typically physical and difficult to change.

10. Material: redesigning the physical system

Bathtub metaphor: If your bathtub has problems, you can replace your dysfunctional bathtub with a new one.

Real life example: In an inefficient road system, its paths can be completely rebuilt.

Limitations: Redesigning the whole system is often expensive and too slow to address the ever changing nature of the problem.

9. Delays: length of delays relative to the rate of the system changes

Bathtub metaphor: If the water heater is on a different floor than the bathtub, it may take minutes after turning the hot water faucet for the hot water to enter the tub (length of delay). By the time the hot water comes on, you may have given up on taking a hot bath (rate of system change).

Real life example: Electric power plants take several years to build, but their demand is ever changing. If electric power plants are in high demand now and are being built, by the time they are finished, renewable energy sources may be more popular.

Limitations: Delays are often uncontrollable and it is typically easier to control the rate of the system change.

8. Negative feedback loops: adjusting the strength of negative feedback loops relative to the impacts they are trying to correct against

Bathtub metaphor: If your baths are too hot, you can turn the cold water faucet ahead of time (negative feedback loop) to balance out the hot water flow (positive feedback loop).

Real Life Example: Taking vitamins, exercising, and eating healthy to prevent sickness

Limitations: Negative feedback loops need to be thought of ahead of time because they are preventative, not reactive measures.

7. Positive Feedback Loops: reducing the gain of a positive feedback loop. When a positive feedback loop is uncontrolled, the system will ultimately collapse.

Bathtub metaphor: If the water is left running, the inflow will overpower the outflow of the tub and therefore the bathtub will flood (“the system
collapses”). Thus, the water inflow needs to be reduced (“reducing the gain”).

**Real Life Example:** The more people that have the flu, the more potential there is to infect others. Instead of trying to strengthen the negative feedback loop by popularizing medicines, the people who have the flu can be quarantined.

**Limitations:** It can be difficult to control positive feedback loops. Quarantining those with the flu may be unethical.

6. **Information: who does and who does not have access to information**

**Bathtub metaphor:** If you don’t know how outflow of water per minute, you cannot determine the appropriate inflow for the bathtub not to flood.

**Real Life Example:** Electricity consumption is lower in a house with the electric meter by the door because residents are more aware of their electricity usage.

**Limitations:** Those in power are often wary about releasing information to the masses, whom may recognize and retaliate against what they see as mistakes.

5. **Rules: incentives, punishments, and constraints of a system**

**Bathtub metaphor:** To prevent the bath from becoming too hot, you restrict the inflow of hot water to 5 minutes only.

**Real Life Example:** The Constitution serves as a basis to American law. The 19th Amendment was passed to grant voting rights to women and include a previously disregarded group in the political and electoral process.

**Limitations:** The power to control rules can be dangerous when placed in a single organization or person because they will often bend the rules to maintain power.

4. **Change & self organize: the ability to evolve a system by creating new structures**

**Bathtub metaphor:** If your back hurts from the hard surface of a bathtub, you can create a waterproof cushion to rest against.

**Real Life Example:** In response to capitalistic agro-businesses, civilians can develop community gardens to create new social and consumer practices.

**Limitations:** Pushing the ability to evolve leaves little room for diversity. If you are fixated with improving phones, you may not consider other communication alternatives.

3. **Goals: changing the goals of the system**

**Real Life Example:** When Hitler came into power, he was able to change the nation’s goal into promoting the “Aryan race” and eliminating those who were not. (It is important to reemphasize that interventions are not all necessarily good, they can be good or bad.)

**Limitations:** As illustrated in the real life example of Nazi Germany, changing the goals of an entire system may be dangerous in that only one set of goals, regardless of how good or bad they are, is promoted.

2. **Paradigms: changing shared public perceptions**

**Real Life Example:** Copernicus and Kepler revealed that the earth is not the center of universe and their discoveries gradually shifted the deeply held geocentric paradigm.

**Limitations:** While changing paradigms may not be expensive or slow, societies tend to resist changes in their belief system.

1. **Transcend Paradigms: realizing that no paradigm is completely true**

**Limitations:** By realizing that no paradigm is truly “right,” people can discard their morality and adopt whatever paradigm helps them reach their goal.