Massachusetts General Hospital
Founding Member, Mass General Brigham

HARVARD
MEDICAL SCHOOL

Leveraging Large Language Models for Automated Causal Loop Diagram Generation

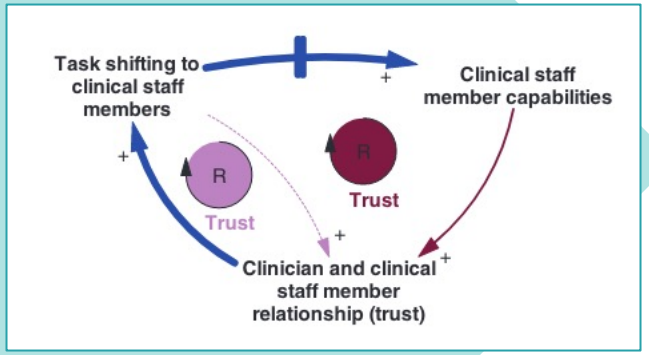
Georgia (Ning-Yuan) Liu[1,2], David Keith[3,4]

[1]MGH Institute for Technology Assessment, Harvard Medical School, Boston, MA, USA
[2]Virginia Polytechnic Institute and State University, Grado Department of Industrial and Systems Engineering, Virginia, USA
[3]Melbourne Business School, University of Melbourne, Melbourne, Australia
[4]Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA, USA

42nd International System Dynamics Conference, August 4th-8th, 2024

Constructing Mental Maps from qualitative data has been manually or semi-automated process

Quotation	Interpretation	
CL01-31) "I certainly like to give feedback when something wasn't done up to my standards and normally that helps… I am a stickler about always [doing x, for example,] … and usually, with new [clinical staff members], they never [do x]. And then, after a couple of times, that usually changes… If I can find them … [then] I do it face to face. [It] normally [takes] a day or two… "[In this department] we all like things done a different way… So usually it takes [clinical staff members] a little bit … to get used to that. But normally they learn." (99/188)	**Phrases**	**CLD Elements**
	• after a couple of times • It normally takes a day or two • it takes [clinical staff members] a little bit	(Delay)
	• I certainly like to give feedback when something wasn't done up to my standards and normally that helps	(Feedback Loop)
	• something wasn't done up to my standards • with new [clinical staff members] they never do x … that usually changes • they learn	Clinical staff member capabilities
	• I certainly like to give feedback • If I can find them, then I do it face to face	Clinician and clinical staff member relationship (trust)
	• I am a stickler about • we all like things done a different way	Task shifting to clinical staff members
	Causal Chain	
	Clinical staff member capabilities →+ Clinician and clinical staff member relationship (trust)→+ Task Shifting to clinical staff members --||→+ Clinical staff member capabilities	
	Coder's Interpretive Notes	
	Capabilities development takes time. This includes 1) the time for the clinicians to find the clinical staff member to bring up a deficiency and 2) the time for the clinical staff member to learn to get it right.	



Source: Tomoaia-Cotisel, A., Allen, S. D., Kim, H., Andersen, D., & Chalabi, Z. (2022). Rigorously interpreted quotation analysis for evaluating causal loop diagrams in Late-Stage conceptualization. *System Dynamics Review*, *38*(1), 41-80.

With the advancement of Generative AI, many manual tasks can be enhanced through the use of LLMs

OpenAI Introduces Innovative Sales Prospecting Tool

Ted Hisokawa Jun 18, 2024 16:11

OpenAI unveils a groundbreaking sales prospecting tool aimed at revolutio sales industry through advanced AI capabilities.

OpenAI has announced a new and innovative sales prospecting tool designed to transform th teams operate. According to OpenAI, this tool leverages advanced artificial intelligence to str enhance the prospecting process, making it more efficient and effective.

AI-Powered Sales Solutions

The newly introduced tool is expected to provide sales professionals with a competitive edge routine tasks and offering data-driven insights. This AI-driven approach aims to reduce the ti

BBC Watch Live

Home News Sport Business Innovation Culture Travel Earth Video Live

Is AI about to transform the legal profession?

18 October 2023 Share

Jane Wakefield
Technology reporter

A number of reports have said that AI will have a large impact on the legal profession

If there was a court case on whether society should embrace artificial intelligence (AI) or reject it, there would likely be a hung jury.

AI NEWS

Microsoft's AI Copilot Is the Beginning of Coding Industry Automation

Copilot is transforming software engineers' work lives, with 1.3 million users, including 50,000 businesses like Goldman Sachs, Ford, and Ernst & Young.

Written By: Jalpa Bhavsar | Last updated: April 18, 2024 7:40 AM | Published April 17, 2024 11:11 PM

Research Problem:

How can we automatically translate text into CLDs?

Experiment Setup

LLM Model Selection:

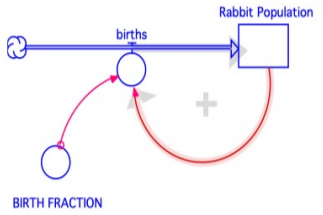
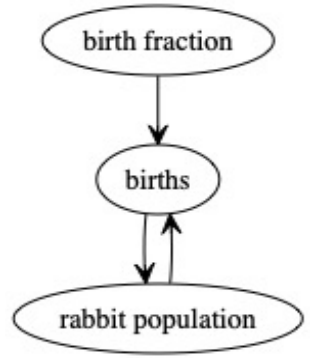
- OpenAI's text-davinci-003 model

Dataset:

- 44 CLDs containing 1-4 feedback loops.
- Text-CLD pairs from leading SD publications:
  - Business Dynamics (Sterman, 2000)
  - The Systems Thinking Playbook (Sweeney & Meadows, 2010)
  - Modeling the Environment: An Introduction to System Dynamics Models of Environmental Systems (Ford, 1999)
  - Thinking in Systems (Meadows, 2009)

Example Text-CLD pair provided to the LLM

Input: Dynamic Hypothesis	Output: Causal Loop Diagram	Output: CLD – Digraph String format	Output: CLD - Digraph

The larger the population, the greater the number of births. increases, the faster the population increases. The more the birth rate increases, the faster the population increases.		digraph {
		"births" -> "rabbit population" [arrowhead = vee]
		"rabbit population"->"births"[arrowhead = vee]
		"birth fraction" -> "births"[arrowhead = vee]
		}
			

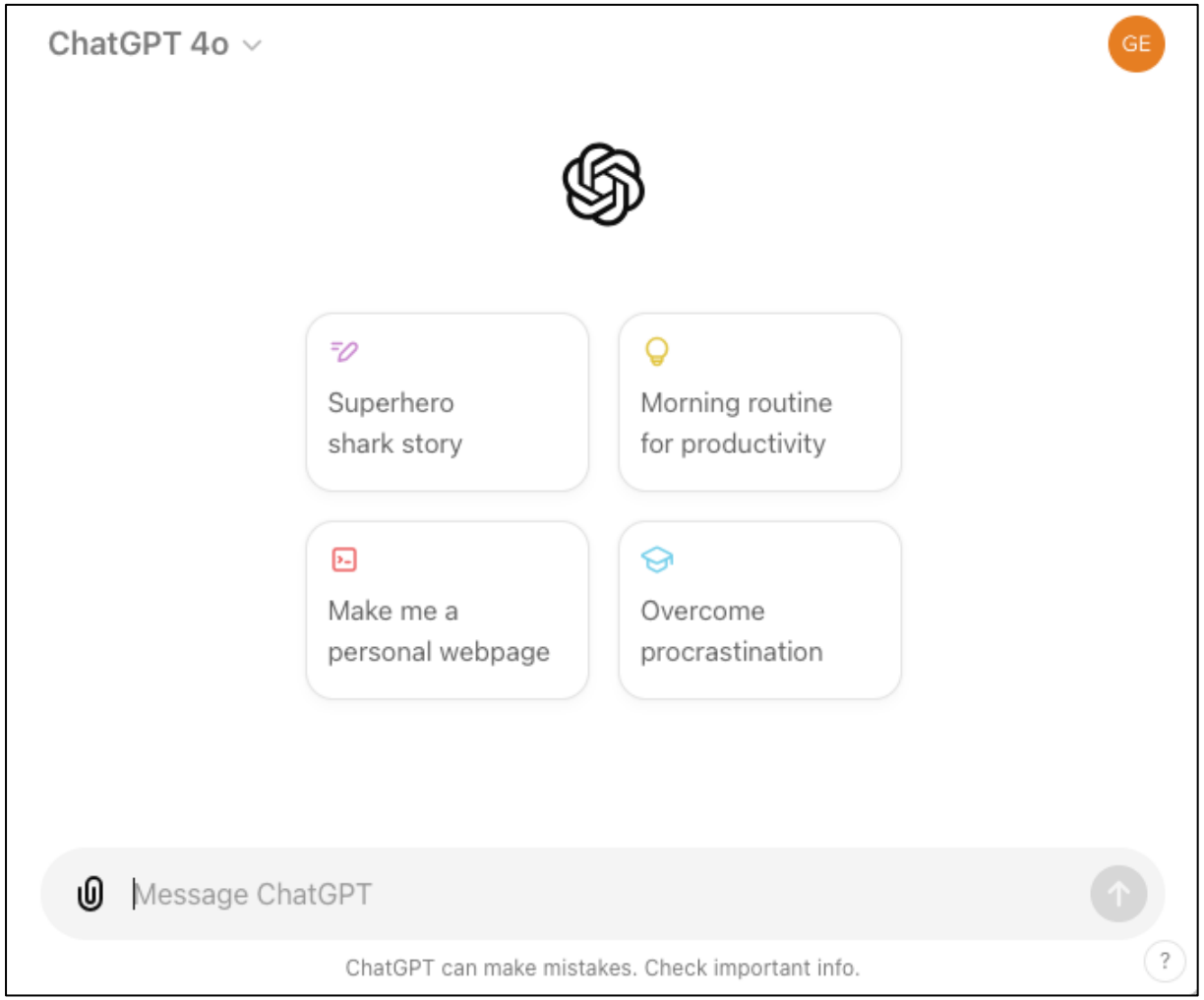
Note: A positive polarity between two variables is represented as arrowhead = vee **(->),** while a negative polarity is represented as arrowhead = tee **(-|).**

We test four types of LLM Prompting Techniques for CLD Generation

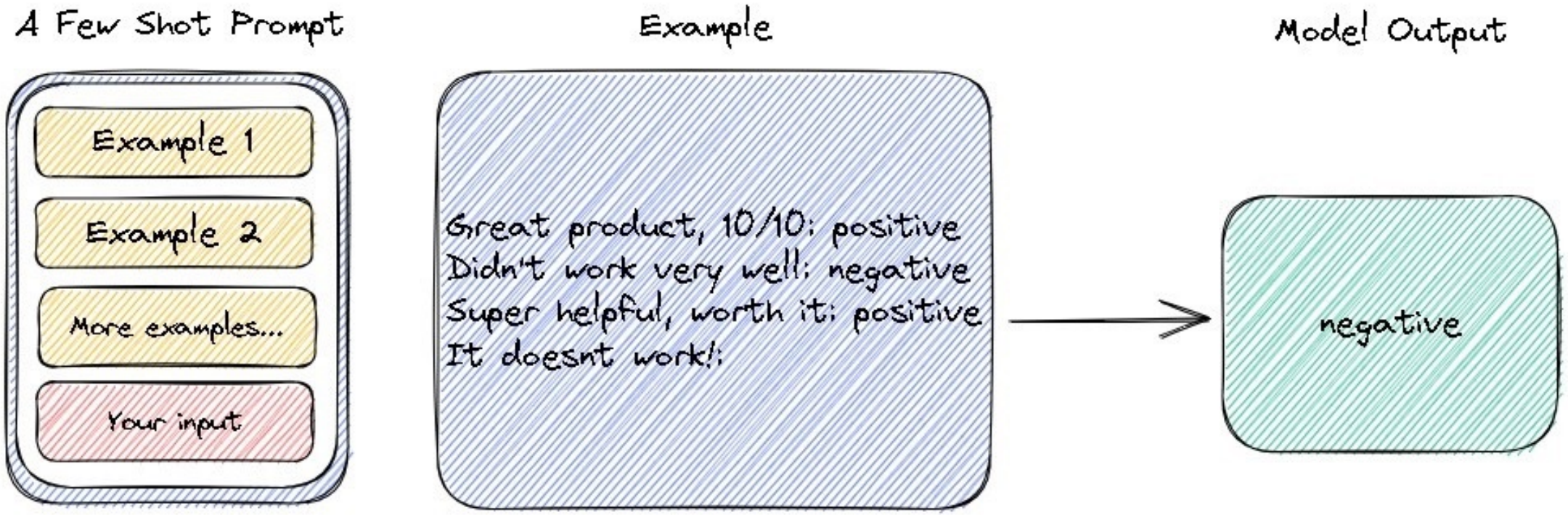
Descriptions of 4 types of prompting techniques

Approach		Description of the Method
1	Zero-shots learning	Baseline. No prior examples are given.
2	Few-shots learning	Given a few examples to LLMs in advanced.
3	Few-shots learning + Guided Prompts	Incorporated curated prompts, i.e., specific instructions to guide the model's response.
4	Two-stage few-shot learning	Mimics the thought process of a human SD modeler, focusing first on variable identification and subsequently on mapping out causal relationships.

Approach 1: Zero-shot Learning



Approach 2: Few Shots Learning



Source: https://www.linkedin.com/pulse/few-shot-prompting-aris-ihwan

Approach 3: Few-shots learning + Guided Prompts

Guided Prompt instructs as follows:

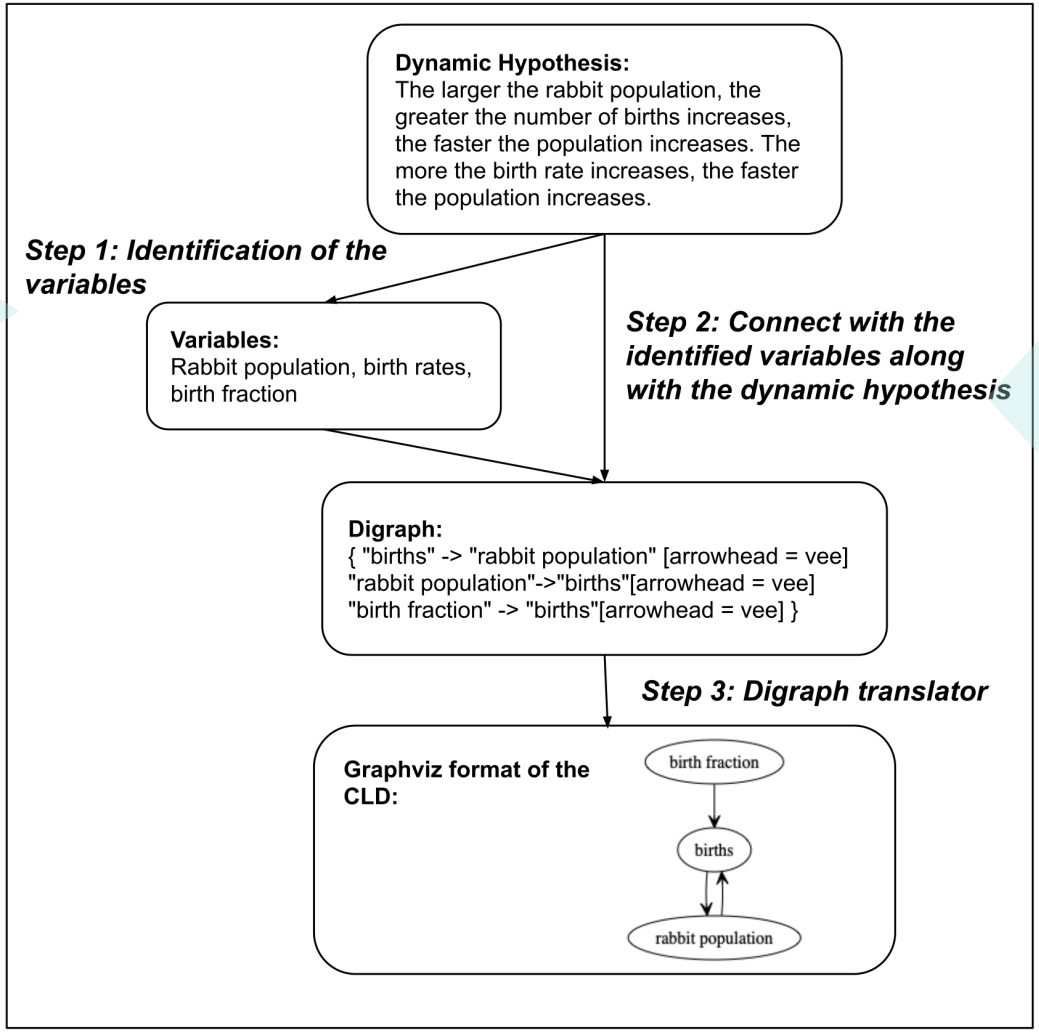
First, Render a list of variable names from the text given. The variable names should be nouns or nouns phrases. The variable names should have a sense of directionality. Chose names for which the the meaning of an increase or decrease is clear.

Second, Render a dot format based on the variable names. A positive relationship is indicated by an arrow from the first variable to the second variable with the sign [vee]. A negative relationship is indicated by an arrow from the first variable to the second variable with the sign [tee].

Approach 4:Two-stage few-shot learning

Render a list of variable names from the text given. Following the rules below =

1. *The variable names should be nouns or nouns phrases.*
2. *The variable names should have a sense of directionality.*



Flow Diagram of the Model Setup for Two-stage Approach

The variables' names will be rendered in DOT format. The steps are as follows:

Step 1: Identify the cause-effect relationship between variable names given the dynamic hypothesis.

Step 2: [arrowhead=vee] indicates a positive relationship. A negative relationship is indicated by [arrowhead=tee].

Step 3: Create a DOT format based on the cause-effect relationship.

- This method is follows to the system dynamics modeling approach outlined by (Sterman, 2000, p152).

Case 1: Single reinforcing loop - Smoking cigarettes

INPUT: “The more my uncle smokes, the more addicted he becomes to the nicotine in his cigarettes. After smoking a few cigarettes a long time ago, my uncle began to develop a need for cigarettes. The need caused him to smoke even more, which produced an even stronger need to smoke. The reinforcing behavior in the addiction process is characteristic of positive feedback.”

The causal loop diagram for the given dynamic hypothesis can be represented as follows:

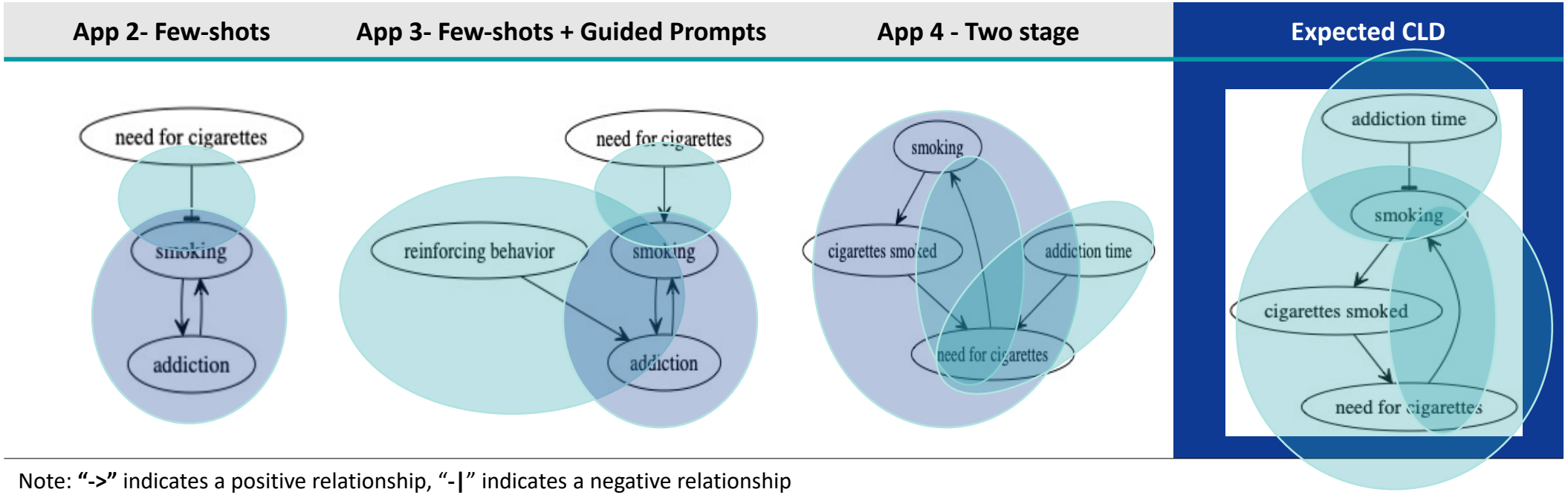
- There is a positive feedback loop between "Smoking" and "Addiction":
  - The arrow from "Smoking" to "Addiction" indicates that an increase in smoking leads to an increase in addiction.
  - The arrow from "Addiction" to "Smoking" indicates that an increase in addiction leads to an increase in smoking
- There is a reinforcing loop between "Addiction" and "Need for cigarettes":
  - The arrow from "Addiction" to "Need for cigarettes" indicates that an increase in addiction leads to an increase in the need for cigarettes.
  - The arrow from "Need for cigarettes" to "Addiction" indicates that an increase in the need for cigarettes leads to an increase in addiction.

Generated Outputs from Approach 1

Case 1: Single reinforcing loop - Smoking cigarettes

INPUT: “The more my uncle smokes, the more addicted he becomes to the nicotine in his cigarettes. After smoking a few cigarettes a long time ago, my uncle began to develop a need for cigarettes. The need caused him to smoke even more, which produced an even stronger need to smoke. The reinforcing behavior in the addiction process is characteristic of positive feedback.”

LLM Generated Outputs & Labeled Graph



Note: **“->”** indicates a positive relationship, “**-|**” indicates a negative relationship

Case 2: Two Balancing Loops – New Car Inventory

INPUT: "Car production builds the inventory of cars at the dealer. A higher inventory leads to a lower market price, and lower market prices cause less car production in the future. If the price were to increase, the retail sale of cars would tend to fall. Retails sales drain the inventory of cars held in stock at the dealership. And a decline in the inventory will cause the dealers to raise their prices in the future."

The causal loop diagram for the given dynamic hypothesis can be represented as follows:

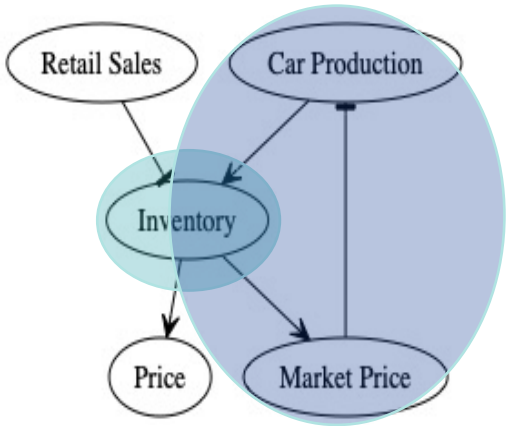
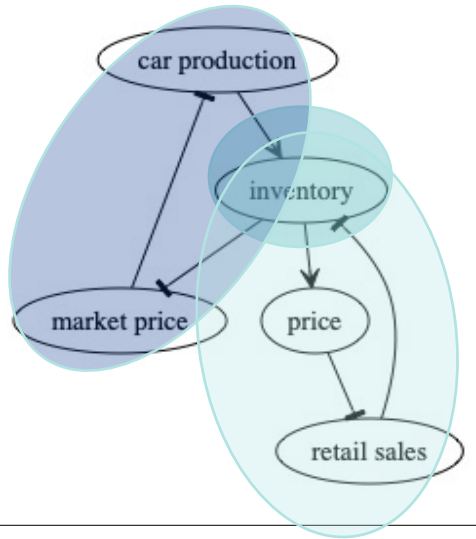
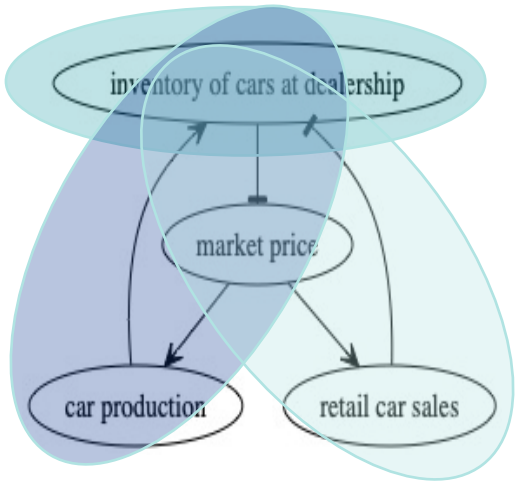
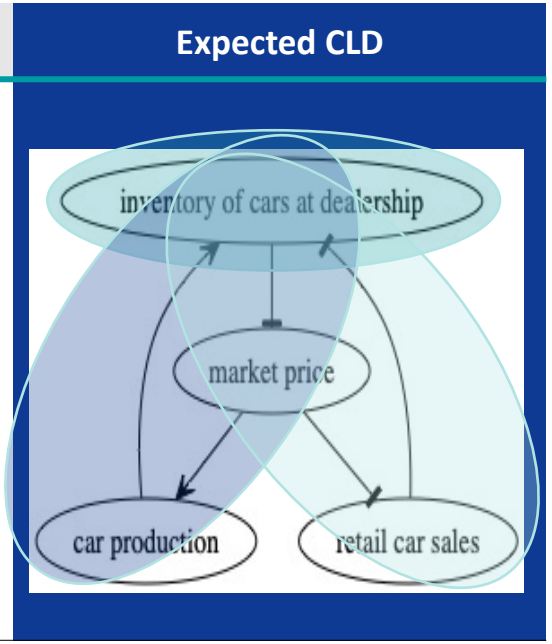
- Car Production --> Inventory of Cars at Dealer --> Market Price --> Car Production
  - Car Production is positively influenced by the Inventory of Cars at Dealer, as a higher inventory allows for more cars to be produced. The Inventory of Cars at Dealer is negatively influenced by the Market Price, as a lower market price leads to a decrease in the inventory.
  - The Market Price is negatively influenced by the Inventory of Cars at Dealer, as a higher inventory leads to a lower market price. Car Production is negatively influenced by the Market Price, as a lower market price leads to a decrease in future car production.
- This causal loop diagram represents a negative feedback loop, where changes in the inventory and market price influence car production, and changes in car production influence the inventory and market price.

Figure 1. Generated Outputs from Approach 1

Case 2: Two Balancing Loops – New Car Inventory

INPUT: "Car production builds the inventory of cars at the dealer. A higher inventory leads to a lower market price, and lower market prices cause less car production in the future. If the price were to increase, the retail sale of cars would tend to fall. Retails sales drain the inventory of cars held in stock at the dealership. And a decline in the inventory will cause the dealers to raise their prices in the future."

Table 3. LLM Generated Outputs & Labeled Graph

App 2- Few-shots	App 3- Few-shots + Guided Prompts	App 4 - Two stage	Expected CLD
			

Note: **"->"** indicates a positive relationship, "**-|**" indicates a negative relationship

Case 3: Two Balancing Loop with Exogenous Variables - Assignment Backlog

INPUT: "The Assignment Backlog is increased by the Assignment Rate and decreased by the Completion Rate. Completion Rate is Workweek (hours per week) times Productivity (tasks completed per hour of effort) times the Effort Devoted to Assignments. Effort Devoted to Assignments is the effort put in by the student compared to the effort required to complete the assignment with high quality. If work pressure is high, the student may choose to cut corners, skim some reading, skip classes, or give less complete answers to the questions in assignments. For example, if a student works 50 hours per week and can do one task per hour with high quality but only does half the work each assignment requires for a good job, then the completion rate would be (50)(1)(.5) = 25 task equivalents per week. Work Pressure determines the workweek and effort devoted to assignments. Work pressure depends on the assignment backlog and the Time Remaining to complete the work: The bigger the backlog or the less time remaining, the higher the workweek needs to be to complete the work on time. Time remaining is of course simply the difference between the Due Date and the current Calendar Time. The two most basic options available to a student faced with high work pressure are to first, work longer hours, thus increasing the completion rate and reducing the backlog , or second, work faster by spending less time on each task, speeding the completion rate and reducing the backlog. Both are negative feedbacks whose goal is to reduce work pressure to a tolerable level."

The causal loop diagram for the given dynamic hypothesis can be represented as follows:

Assignment Backlog <--- Assignment Rate --- Completion Rate --- Effort Devoted to Assignments --- Work Pressure --- Workweek --- Time Remaining --- Assignment Backlog

- The Assignment Backlog is increased by the Assignment Rate, indicating that more assignments are being added to the backlog.
- The Assignment Backlog is decreased by the Completion Rate, indicating that completed assignments are being removed from the backlog.
- The Completion Rate is determined by the Workweek, Productivity, and Effort Devoted to Assignments.
- The Effort Devoted to Assignments is determined by the comparison between the effort put in by the student and the effort required to complete the assignment with high quality.
- The Work Pressure is determined by the Assignment Backlog and the Time Remaining.
- The Workweek is determined by the Work Pressure, indicating that higher work pressure leads to longer work hours.
- The Time Remaining is determined by the difference between the Due Date and the current Calendar Time.
- The Assignment Backlog is influenced by the Time Remaining, indicating that less time remaining increases the backlog.

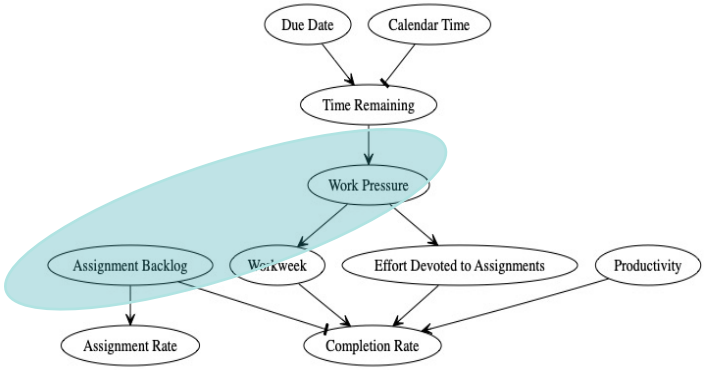
There are two negative feedback loops in the system:
1. The first negative feedback loop involves the Workweek and the Completion Rate, which aims to reduce the Assignment Backlog by increasing the completion rate through longer work hours.
2. The second negative feedback loop involves the Workweek and the Assignment Backlog, which aims to reduce the Work Pressure by decreasing the backlog through longer work hours.

Both negative feedback loops work towards reducing work pressure to a tolerable level.
Overall, this causal loop diagram captures the relationships between the different variables and their influence on the Assignment Backlog and Work Pressure in the given dynamic hypothesis.

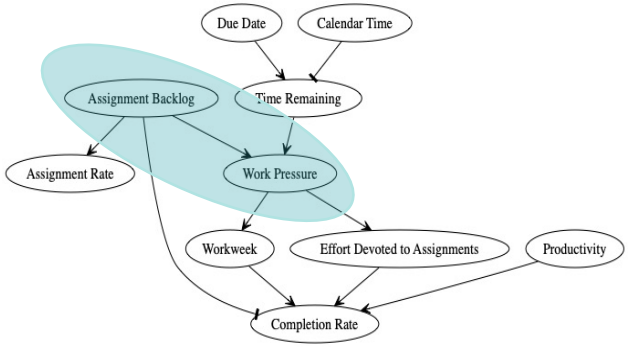
Figure 1. Generated Outputs from Approach 1

Case 3: Two Balancing Loop with Exogenous Variables - Assignment Backlog

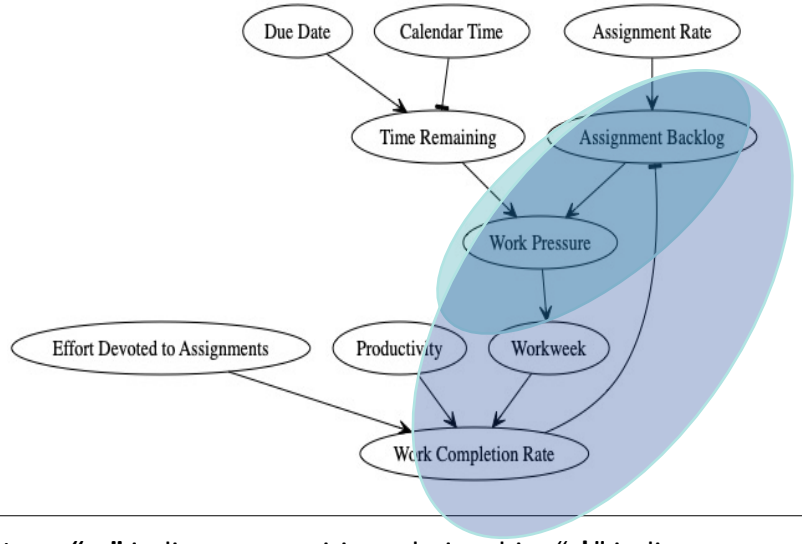
App 2- Few-shots



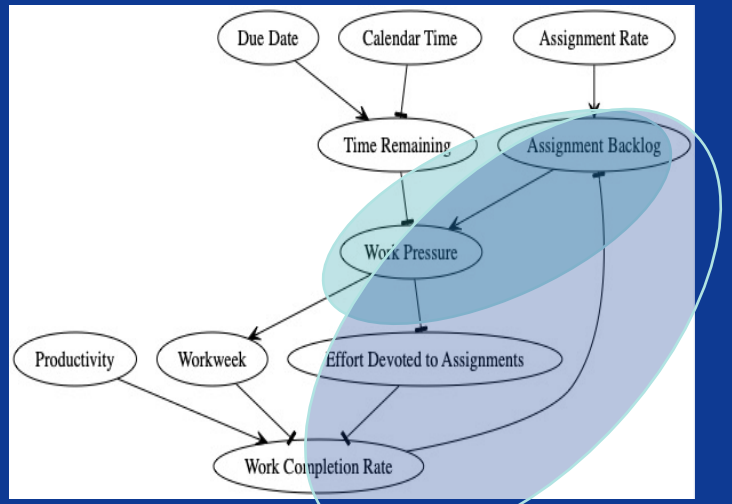
App 3- Few-shots + Guided Prompts



App 4 - Two stage



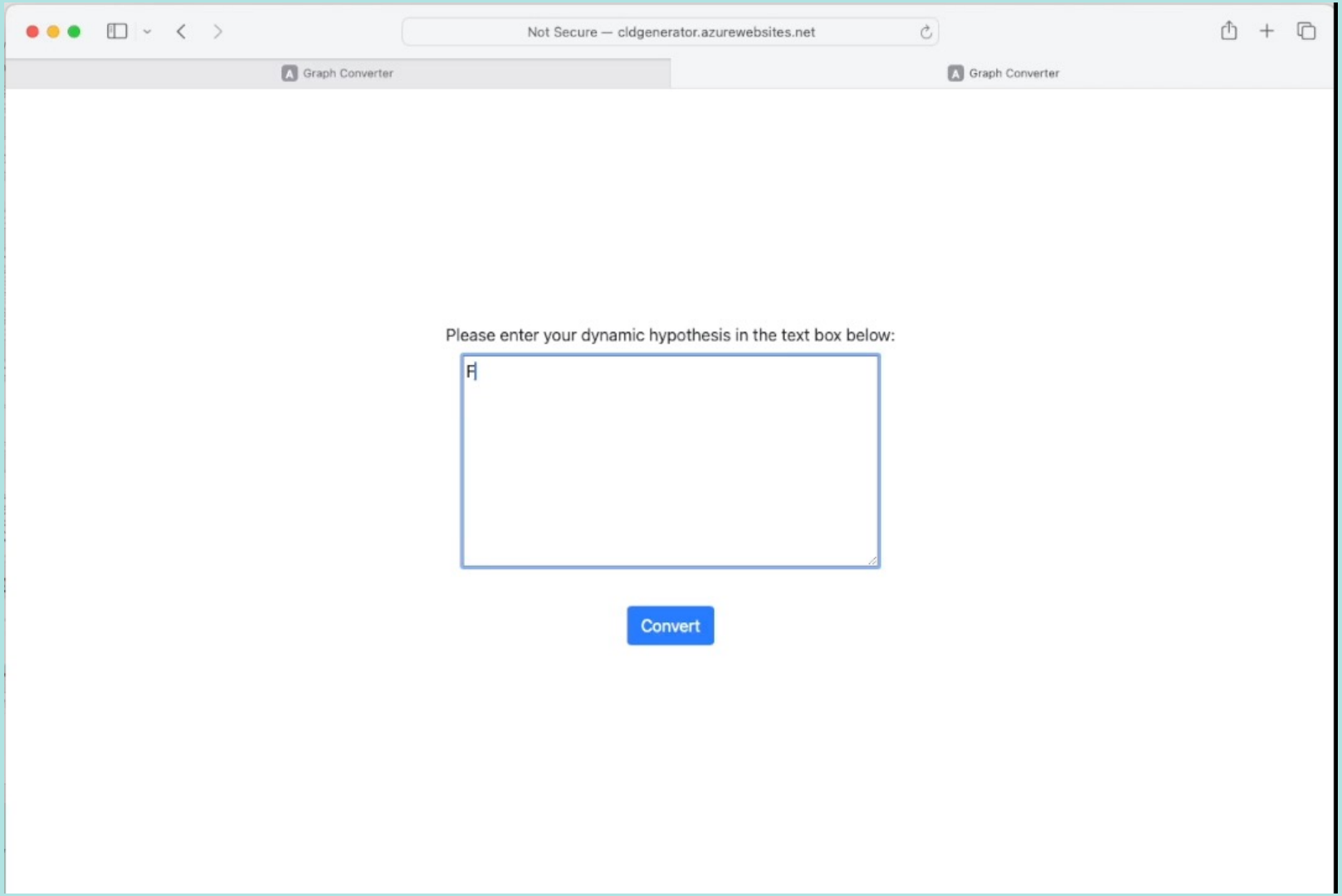
Expected CLD



Note: **"->"** indicates a positive relationship, "**-|**" indicates a negative relationship

CLD Generator Demo

SCAN ME



Link to the website: http://cldgenerator.azurewebsites.net

Conclusion

Demonstrated potential of LLMs to accelerate analysis of complex systems

- LLMs can generate CLDs comparable to expert human modelers for simple feedback structures
- Curated prompting techniques improve CLD generation accuracy

Benefits of integrating LLMs into SD toolkit

- Accelerates CLD development process
- Lowers barriers for novice modelers
- Aids growth of the SD field
- Enhances quality standards in SD modeling

Useful for Group Model-Building (GMB) sessions

- Translates vast interview transcripts into mental maps and CLDs
- Translates news articles into CLDs

Discussion & Future Work

- Utilizing Unstructured Data
- Enhanced Prompting Techniques
- Data repository for qualitative data

Leveraging Large Language Models for Automated Causal Loop Diagram Generation

Thank you!
Questions?

Georgia Ning-Yuan Liu
Postdoctoral research fellow @ Harvard
| Formerly @GoogleX | @VirginiaTech

For more information, you can contact me through:

- Email: gliu26@mgh.harvard.edu
- LinkedIn: www.linkedin.com/in/ngeorgialiu


Mass General Brigham