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Combining Causal Loop Diagrams, Behavior-Over-Time Graphs, and Domain-Specific Languages to Structure and Explore Complex Problems

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Introduction

Abstract

Status Quo:

- Causal Loop Diagrams (CLDs): A flexible and valuable tool used in strategic decision-making and management
- Behavior-Over-Time Graphs (BOTGs): An initial step to understanding the dynamic patterns and the quantitative scale of the problem under study; especially helpful in capturing dynamic, quantitative hypotheses about the problem at hand.
- The crucial dissemination of CLDs, BOTGs and the possible learnings beyond the project-team is challenging

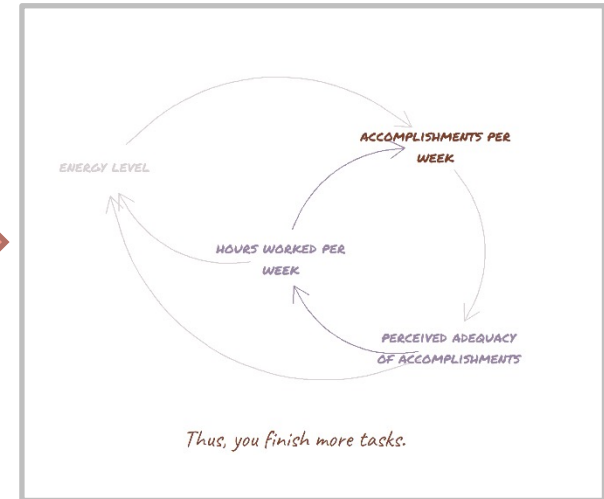
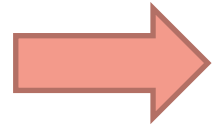
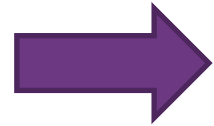
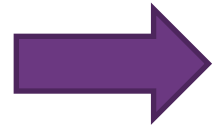
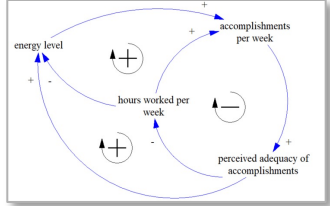
Proposed solution:

- We present a Domain-Specific Language (DSL) that allows generating visual representations of CLDs enriched with BOTGs.
- With the DSL, we can illustrate the structure, dynamic patterns, and quantitative scale of the problem under study step-by-step, allowing exploration and reflection by a broad audience.

Introduction

Targeted Use Case

Causal Loop Diagram



1 Create your CLD using a System Dynamics-Tool (i.e. Vensim)

2 Export the CLD as an *.mdl-File

3 Write a small R Script to explain the CLD to your Audience using new DSL Commands

4 Get a new Representation of your CLD which is easier to grasp



R-Package with
Functionality for CLD-
Visualization (the DSL)

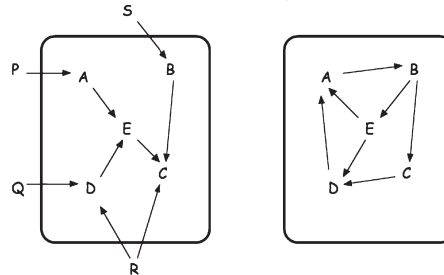


Methodology

Methodology

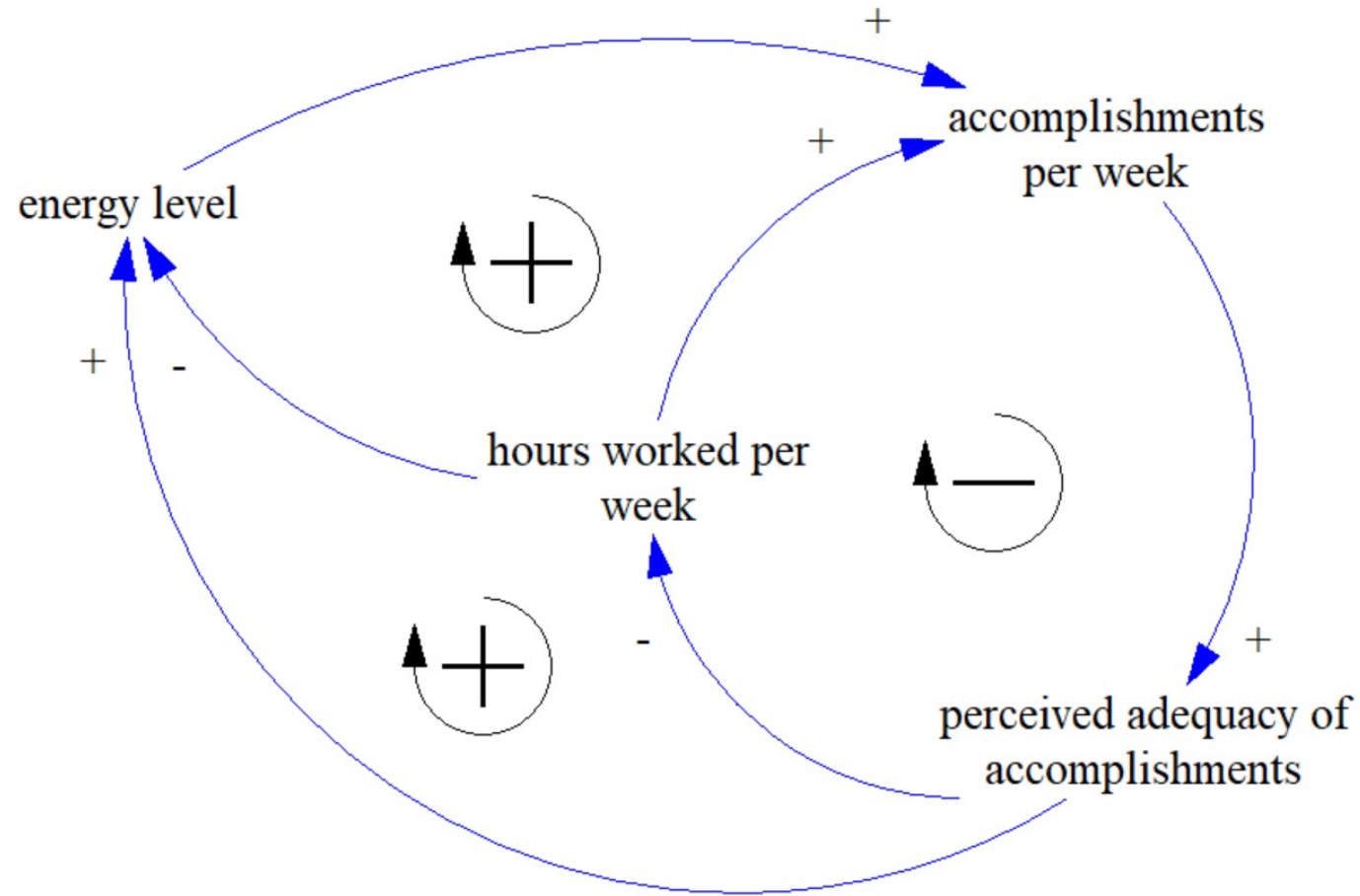
System Dynamics (SD)

- Method for **modeling and simulation of complex systems** that adapts control theory to a broader set of problems (Forrester1961)
- Two key elements differentiate SD from other methods in Operations Research:
 - i. SD models *generate dynamics endogenously*. Many classical SD models show how flawed internal policies of industries or cities generate decay without external limiting factors (Richardson 2011).



- ii. SD *makes mental models explicit* by modeling them as CLDs. Making the models explicit is the basis for a deeper understanding of a messy situation, for revising mental models, for allowing double-loop learning to occur and for taking strategic decisions (Torres2017 ¹, Lane1992 ¹, Vennix1999, Paich1993 ²)

Causal Loop Diagrams – What they are



Methodology

Usage of Causal Loop Diagrams

We use CLDs

- i. to structure complex problems;
- ii. to explore complex decision-making situations in participatory modeling processes;
- iii. to foster learning among stakeholders involved in the modeling process;
- iv. as a basis for simulation models, and
- v. to communicate results of simulation studies

Methodology

SD & CLDs: General Findings

- System Dynamics is best applied to relatively complex and unstructured problems where endogenous dynamics generate (unwanted) dynamics (Hovmand 2014, Lane 1999, Vennix 1999)
- Customer involvement is crucial in such problems: Confidence in models and simulation results is necessary for implementation to happen (Black 2013, Wolstenholme 1999, Hovmand 2014)
- While CLDs are valuable *in* such projects, their dissemination *out* of the project is unlikely (Wolstenholme 1999, Hovmand 2014)
- Relevant stakeholders (senior decision-makers) generally don't have the knowledge to interpret CLDs (Wolstenholme 1999). They don't like being "taught" (Wolstenholme 1999).

So the question is: How can we strengthen the dissemination of CLDs outside the project team?

Methodology

R

- open-source programming language and software environment designed for statistical computing, data science, and graphics (Ihaka & Gentleman, 1996)
- R is a very flexible language
 - Computing on the language is straightforward in R (Wickham 2015, Mailund 2018)
 - The combination of first-class environments, lexical scoping, non-standard evaluation, and meta-programming make R especially well suited to support the creation of embedded Domain Specific Languages (DSLs) (Wickham, 2015)
- We use R at the Institute of Modeling and Simulation
 - sim911: A package published on CRAN to analyze rescue-service based data
 - Communication: Shiny Apps, R Markdown

Methodology

Domain-Specific Languages

Domain-specific language (noun): a computer programming language of limited expressiveness focused on a particular domain (Fowler, 2011).

Solution



Solution

DSL Functionality

- **IMPORT** a CLD from Vensim
- **LINK** group CLD elements (using existing Causal Chains)
- **DESCRIBE** groups of CLD elements with textual descriptions and reference modes
- **PLOT** the resulting CLD

Solution

DSL Grammar - Sentences

```
DSL_SENTENCE ::= DSL_EXPRESSION  
              | DSL_EXPRESSION %>% PLOT
```

```
DSL_EXPRESSION ::= IMPORT  
                | DSL_EXPRESSION %>% LINK  
                | DSL_EXPRESSION %>% DESCRIBE
```

Solution

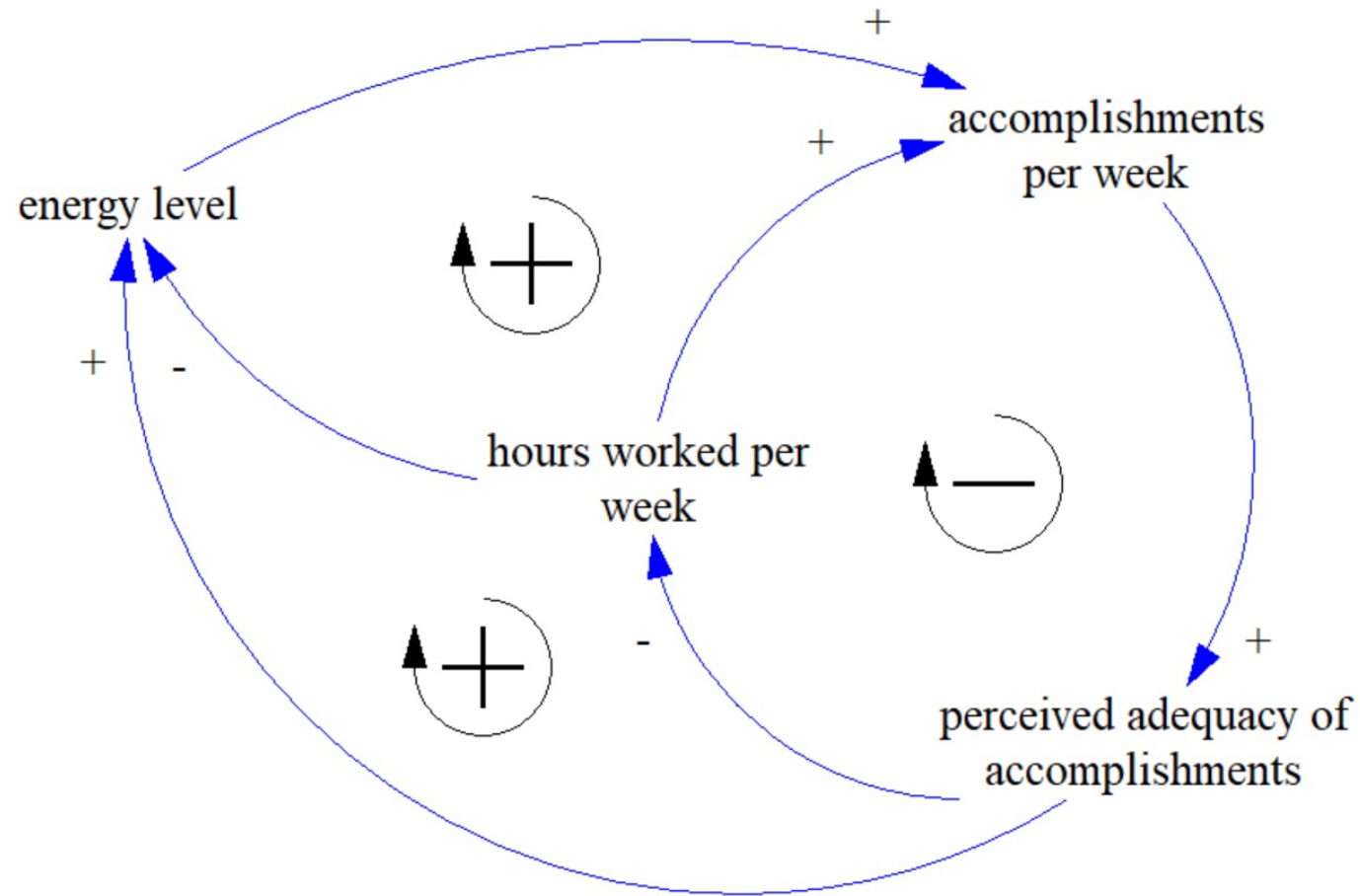
DSL Grammar – Causal Chains

```
LINK_EXPRESSION ::= CAUSAL_CHAIN  
                | CAUSAL_CHAIN , LINK_EXPRESSION
```

```
CAUSAL_CHAIN ::= VARIABLE  
             | CAUSAL_CHAIN %->% VARIABLE
```

The DSL in Action

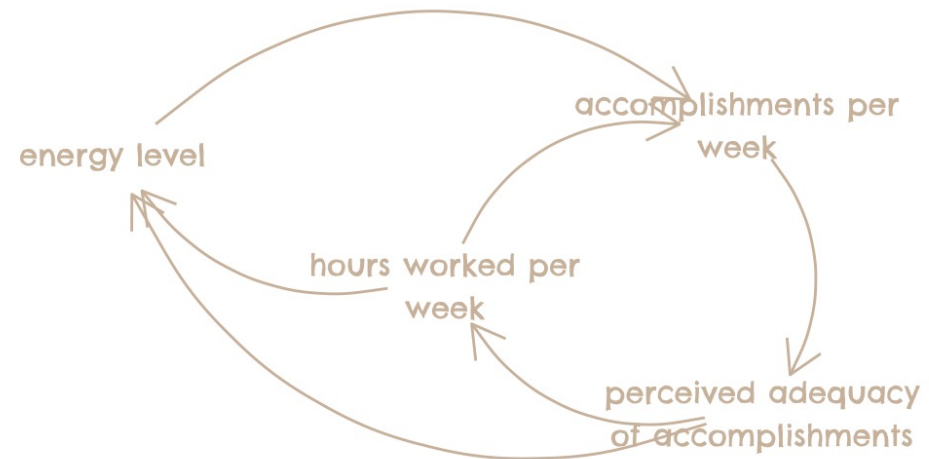
The original CLD «burnout model» (Homer 1985)



The DSL in Action

Default plot

```
cld %>% plot()
```



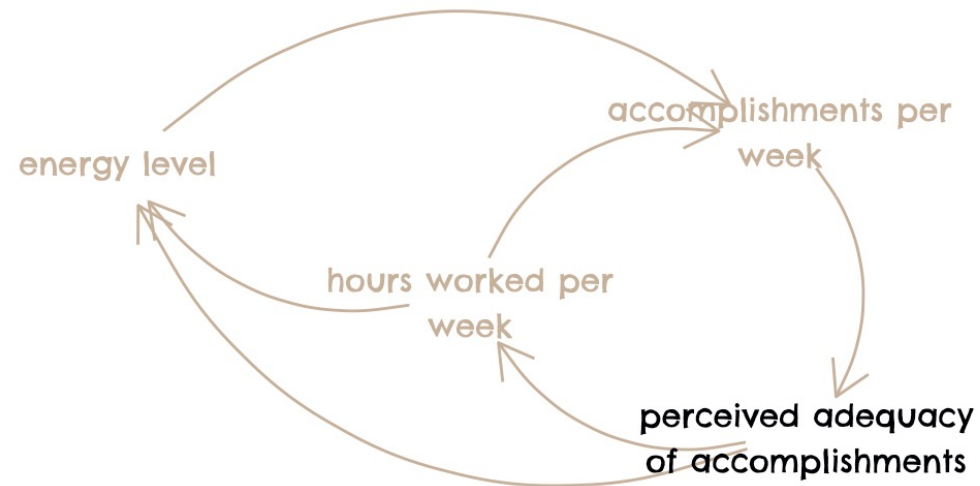
The DSL in Action

Highlighting a single variable

```
cld %>%
```

```
  link(`perceived adequacy`) %>%
```

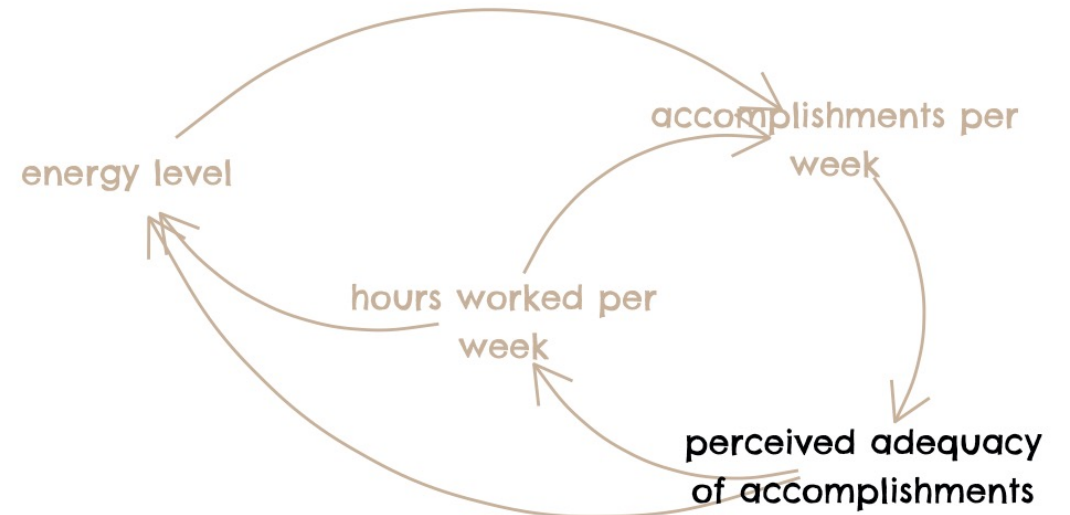
```
  plot()
```



The DSL in Action

Start a «narrative»

```
cld %>%  
  link(`perceived adequacy`) %>%  
  describe(type = "text", "You (or your boss)  
  are unhappy with your accomplishments.") %>%  
  plot()
```



You (or your boss) are unhappy with your accomplishments.

The DSL in Action

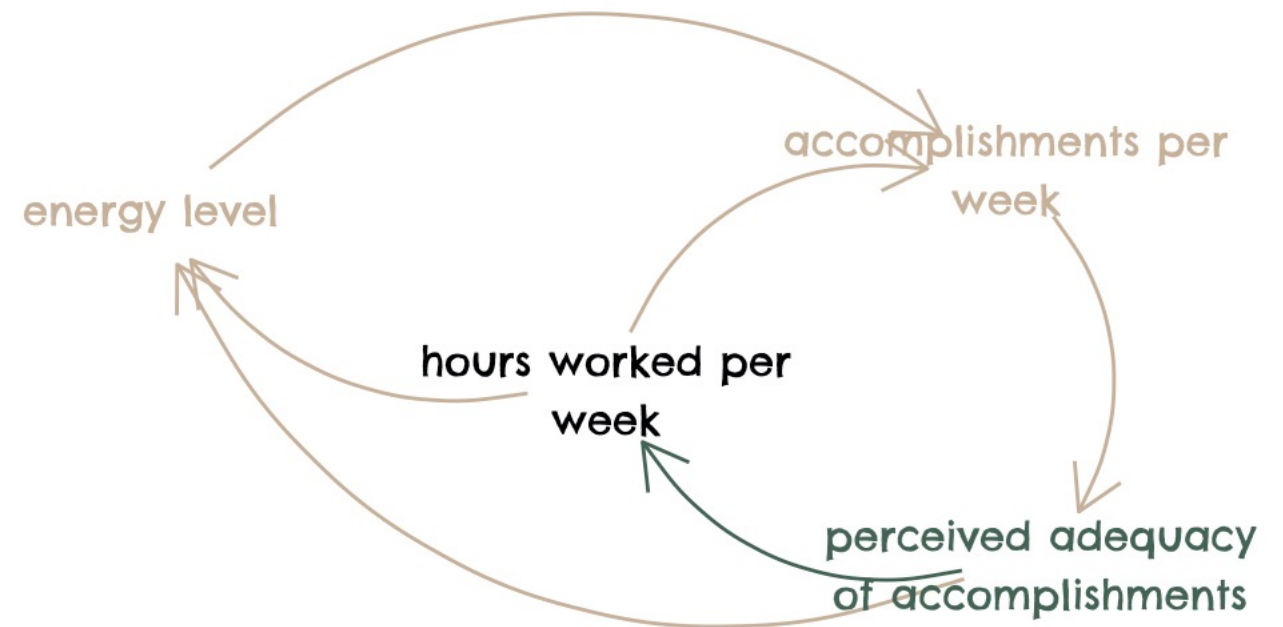
Define a causal chain

```
clد %>%
```

```
  link(`perceived adequacy` %>% `hours worked`) %>%
```

```
  link(`hours worked`) %>%
```

```
  plot()
```



The DSL in Action

Continue the «narrative»

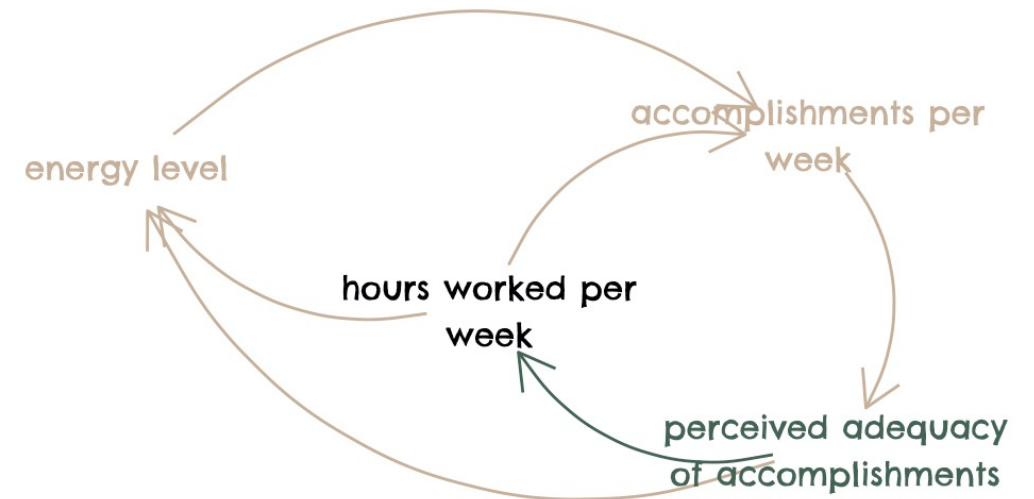
```
c1d %>%
```

```
  link(`perceived adequacy` %>% `hours worked`) %>%
```

```
  link(`hours worked`) %>%
```

```
  describe(type = "text", "As a reaction you start  
    to work more hours per week.") %>%
```

```
  plot()
```

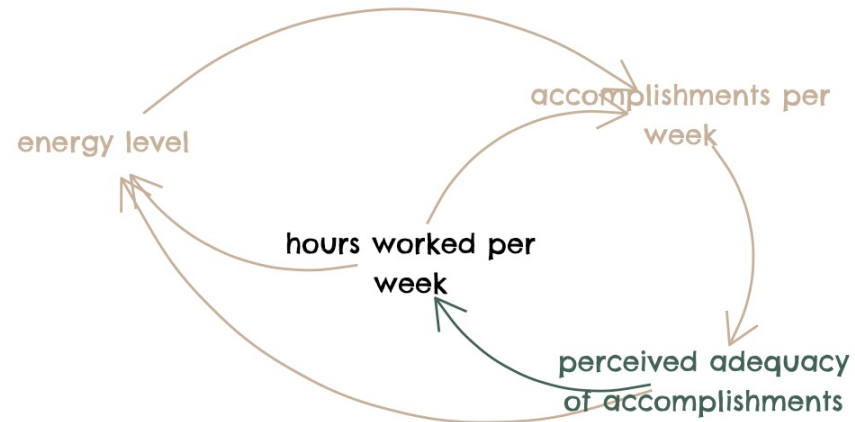
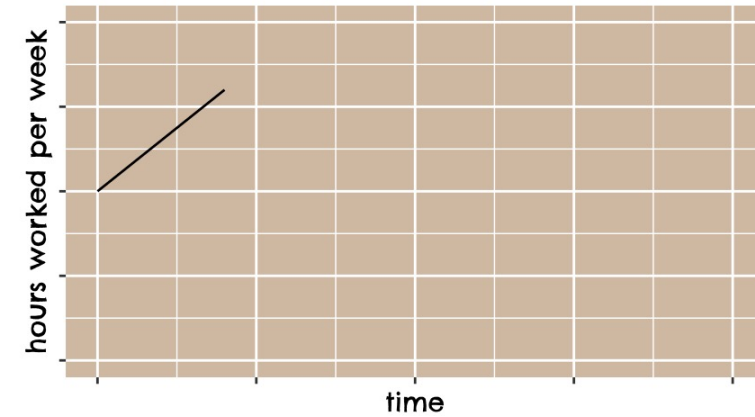


As a reaction you start to work more hours per week.

The DSL in Action

Add a Behavior-Over-Time Graph

```
cld %>%  
  link(`perceived adequacy` %->% `hours worked`) %>%  
  link(`hours worked`) %>%  
  describe(type = "text", "As a reaction you start to work more  
    hours per week.") %>%  
  describe(type = "ref_mode", 0/.5 %-% .2/.8) %>%  
  plot()
```

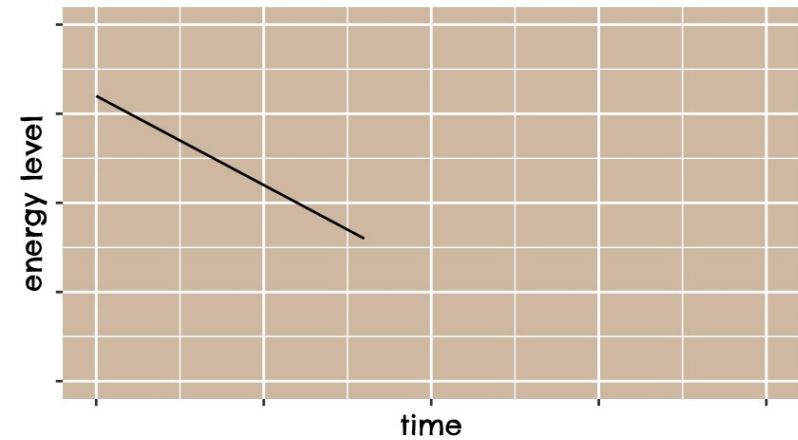


As a reaction you start to work more hours per week.

The DSL in Action

Different curve types

```
cld %>%  
  link(`energy`) %>%  
  describe(type = "text", "Your energy level starts declining.") %>%  
  describe(type = "ref_mode", 0/.8 %-% .4/.4) %>%  
  plot()
```

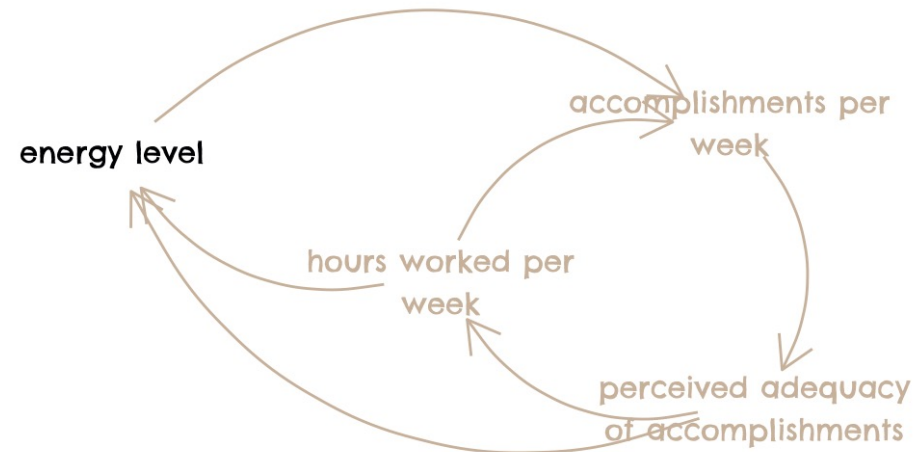
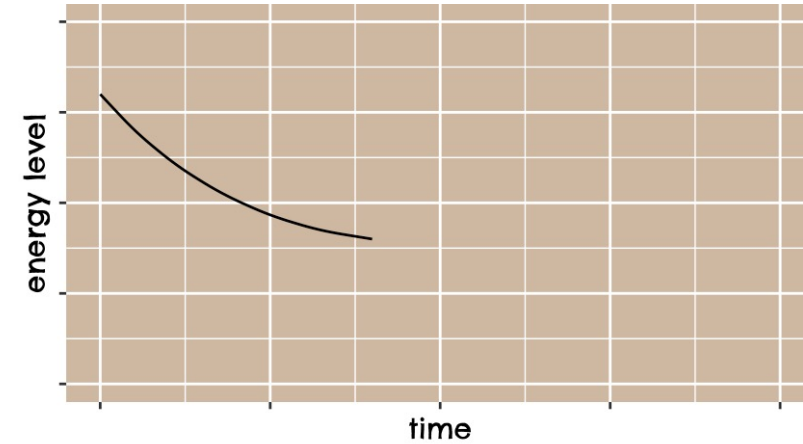


Your energy level starts declining.

The DSL in Action

Different curve types

```
cld %>%  
  link(`energy`) %>%  
  describe(type = "text", "Your energy level starts declining.") %>%  
  describe(type = "ref_mode", 0/.8 %>% .4/.4) %>%  
  plot()
```

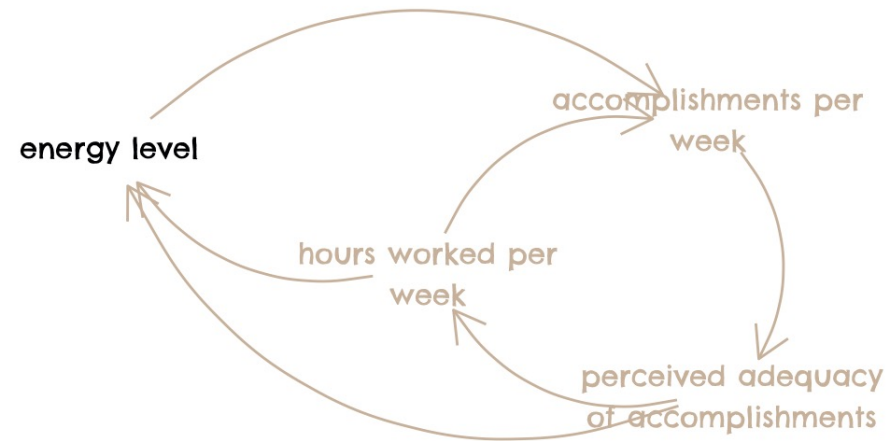
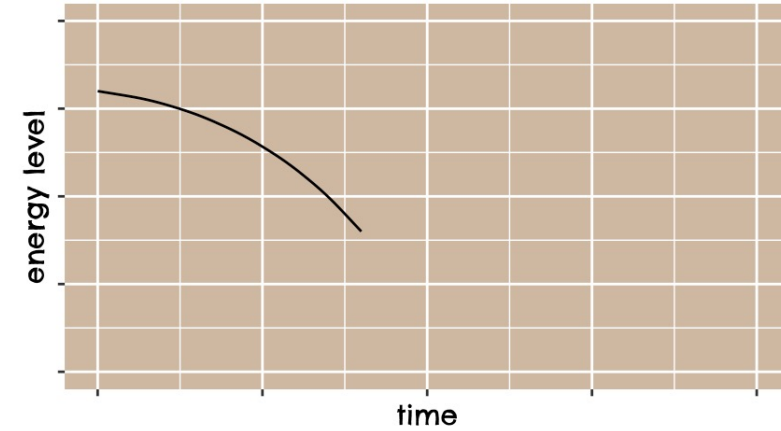


Your energy level starts declining.

The DSL in Action

Different curve types

```
cld %>%  
  link(`energy`) %>%  
  describe(type = "text", "Your energy level starts declining.") %>%  
  describe(type = "ref_mode", 0/.8 %C% .4/.4) %>%  
  plot()
```



Your energy level starts declining.

Conclusions

Conclusions

A New Approach to Communicate CLDs

- DSL allows us to explain CLDs **bit-by-bit**
 - To ensure that the CLD's **circular structure is not concealed**, the whole model is always kept visible (greyed out)
 - Highlighting certain elements helps to **break the CLD into understandable pieces**
- **Compensate for the information loss*** by providing additional descriptions
- **Reach a broader target audience** through a less technical look

Conclusions

Communicate Systemic Complexity – Three connected layers

Textual Description <> Causal Structure <> Behavior-Over-Time Graphs

- 1. Textual Description:** The first „touch“, accessible to all stakeholders, „narratives“
- 2. Causal Structure:** Ensure that the narratives and variables are being interpreted as „belonging together“
- 3. Behavior-Over-Time Graphs:** Hypothesize about the behaviour of the problem under study

Conclusions

Embedded DSL in R

- To implement the solution in the form of an embedded DSL in R proves valuable
- Thanks to the DSL approach, we can write short, simple, and elegant code, which in turn provides for excellent prototyping possibilities
- R's properties allowed us to find surprisingly simple notations, grammars, and suitable plotting possibilities.

Conclusions

Applications

In numerous customer projects, the DSL turned out to be a very valuable tool:

- i. to develop a common problem understanding;
- ii. to communicate that understanding to stakeholders beyond the project team;
- iii. to foster strategic decision-making.

A particular appealing application of the developed DSL is a project funded by 'Innosuisse - Swiss Innovation Agency' in the field of policy design for elderly care.

Resources

- R-Code is hosted at: <https://github.com/ims-fhs/cld>
- Short paper about (parts) of the DSL: <https://www.springer.com/gp/book/9783030484385>
- Models from the «Work-Life Balance 4.0» project (German):
<https://www.fhsg.ch/de/forschung-dienstleistungen/institute-zentren/institut-fuer-soziale-arbeit-und-raeume/integration-und-arbeit/work-life-balance-40/wirkungszusammenhaenge/>
- The “Burnout Model” App (German): <https://fhsg.shinyapps.io/burnout/>
- Information on «Who Cares», the on-going project in elderly care:
<https://www.fhsg.ch/de/forschung-dienstleistungen/institute-zentren/institut-fuer-modellbildung-simulation/care-system-design/verbesserte-planung-der-langzeitpflege/>

Discussion



... I'm looking forward to further discuss the case. adrian.staempfli@ost.ch

Thank you!