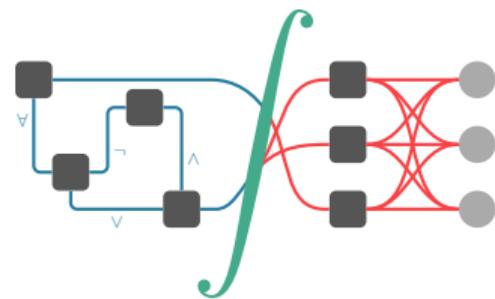


Unifying and scaling neurosymbolic AI from abstraction to application

Lennert De Smet



I actually did something useful during my PhD!

I actually did something useful during my PhD!
(but I did not really finish it yet...)

Electric vehicles (EVs) and solar panels challenge the energy grid



Peak consumption goes up
because more people charge their EVs at the same time

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Home production goes up
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Electric vehicles (EVs) and solar panels challenge the energy grid



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Question

What does it mean for you?

Blackouts and failures are unavoidable

Blackouts and failures are unavoidable
if we don't modernise the cables of the energy grid

Modernising the energy grid has to be done smartly
to be quick and avoid high cost

Solution? Let's just put all new cables in the ground

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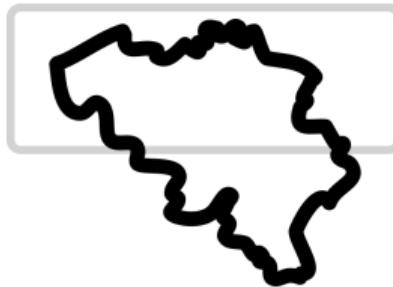
Well... ...that's a lot of cables, money and time



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40 075 km

Flemish cables

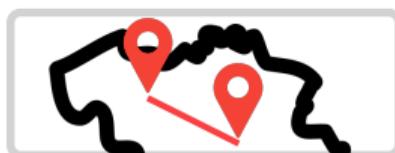
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120 km

Leuven-Maldegem



40 075 km

Flemish cables

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120 km

Leuven-Maldegem

More than $\times 334$

40 075 km

Flemish cables



A perfect model could tell us where to modernise

Maps of the grid

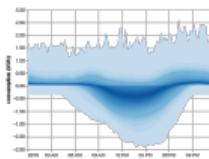


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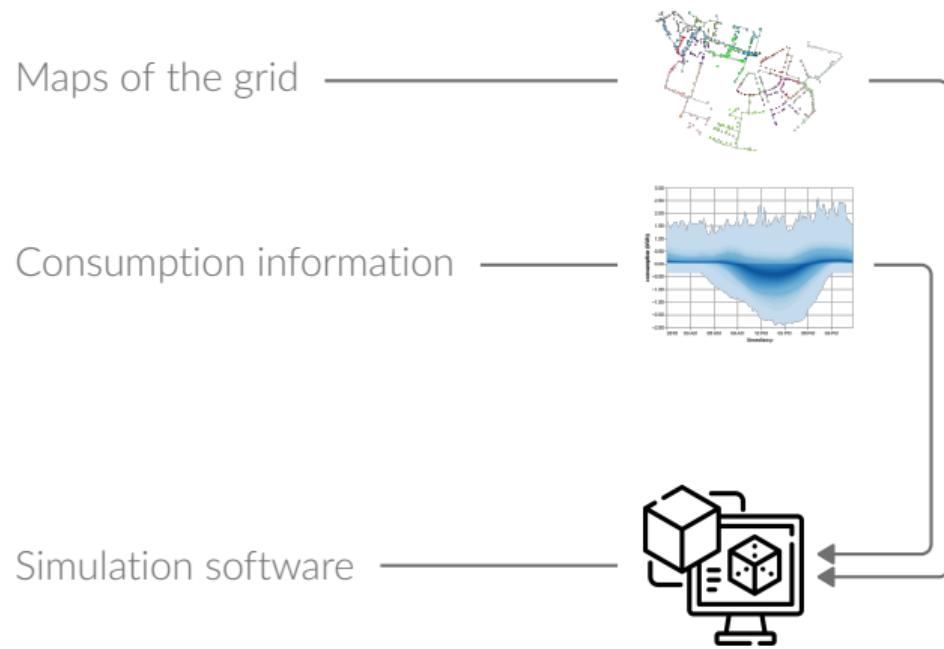
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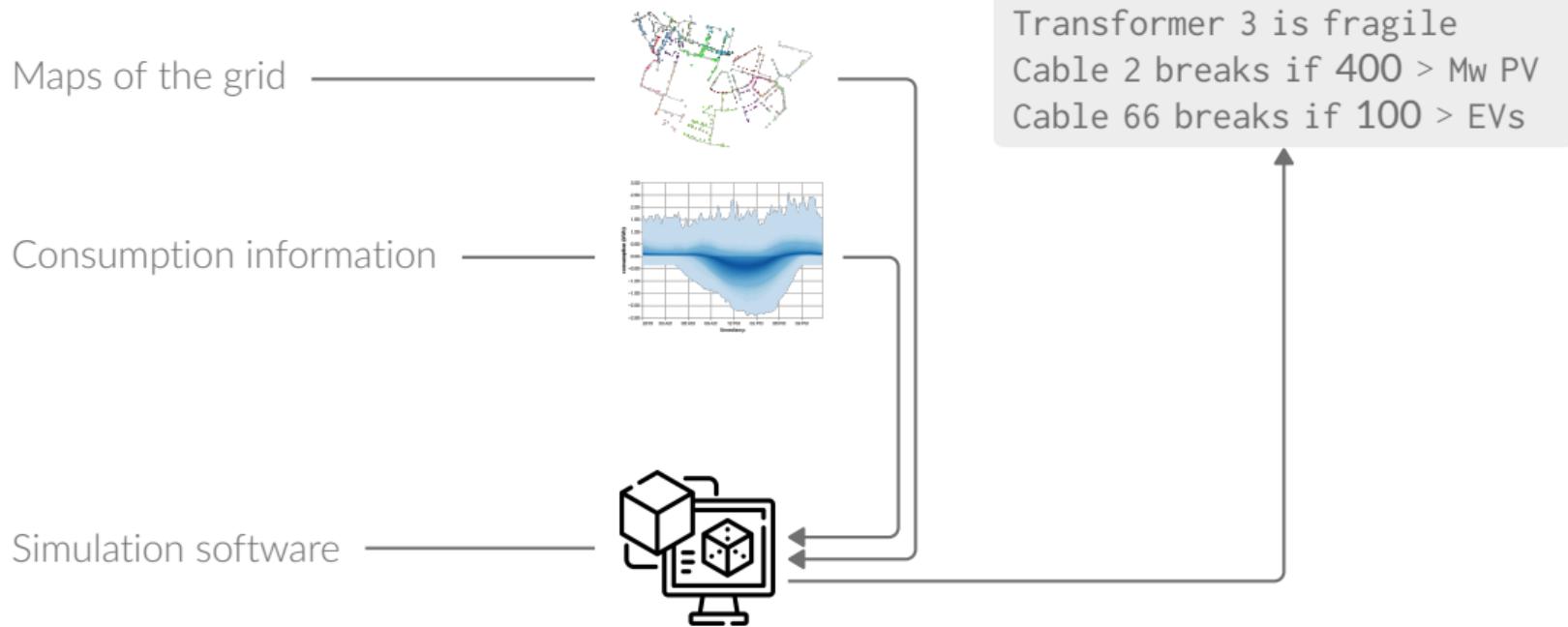
Consumption information



A perfect model could tell us where to modernise



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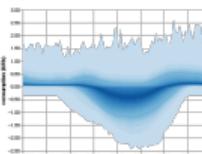


A perfect model could tell us where to modernise
but we don't have correct maps

Maps of the grid



Consumption information

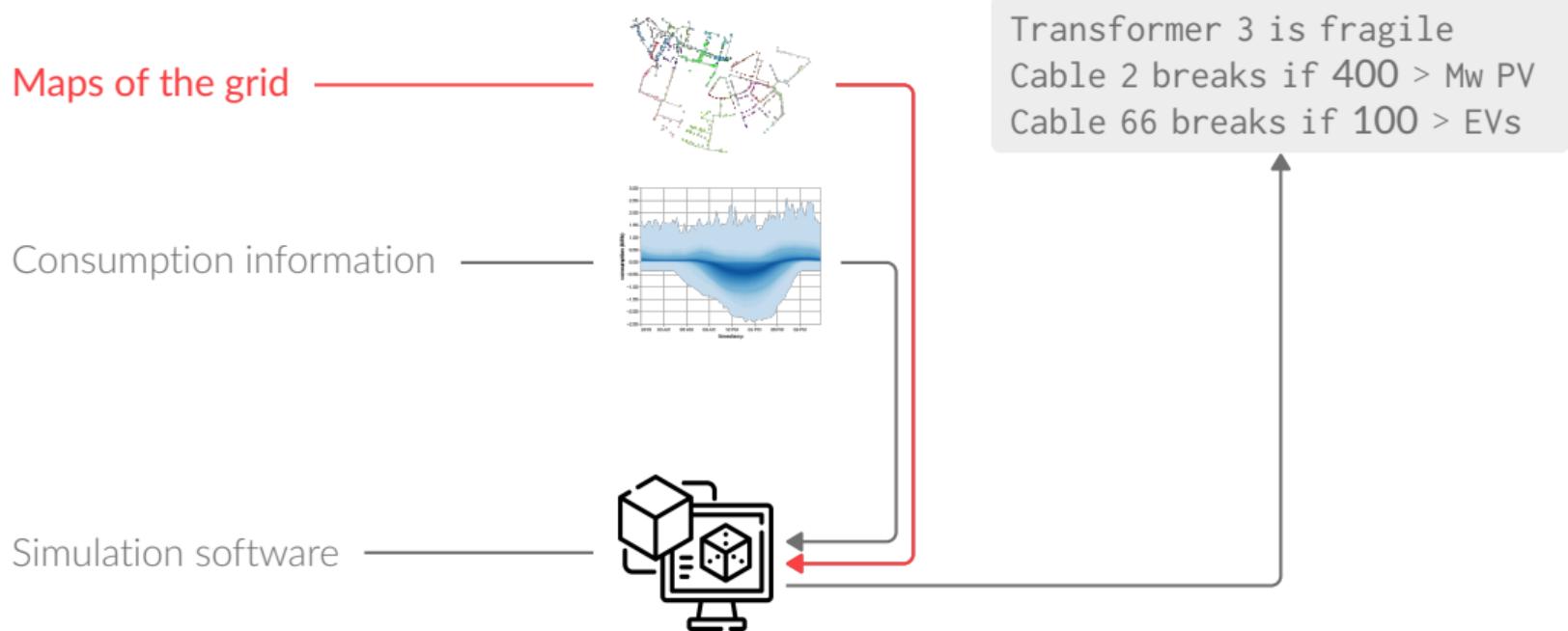


Simulation software

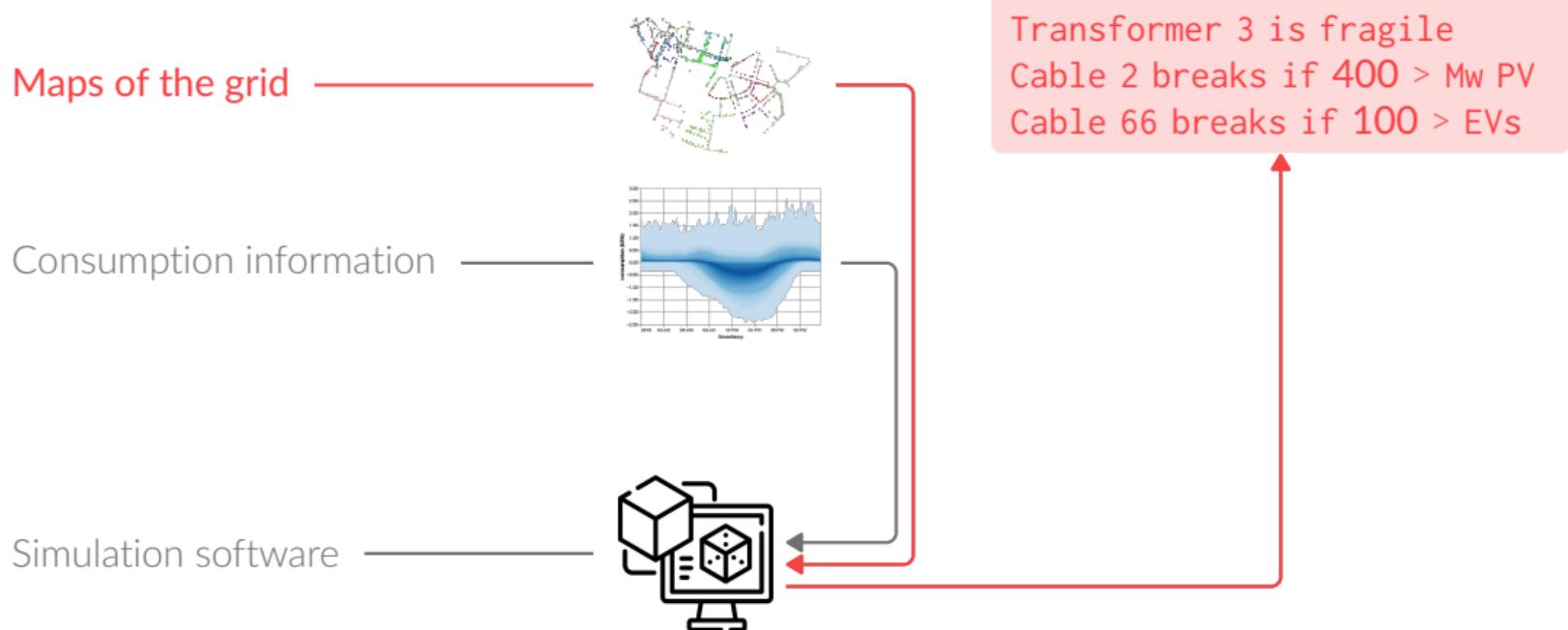


Transformer 3 is fragile
Cable 2 breaks if $400 > \text{Mw PV}$
Cable 66 breaks if $100 > \text{EVs}$

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but we don't have correct maps



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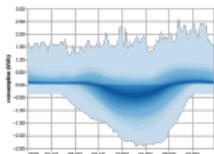
A perfect model with experts could tell us where to modernise

Maps of the grid



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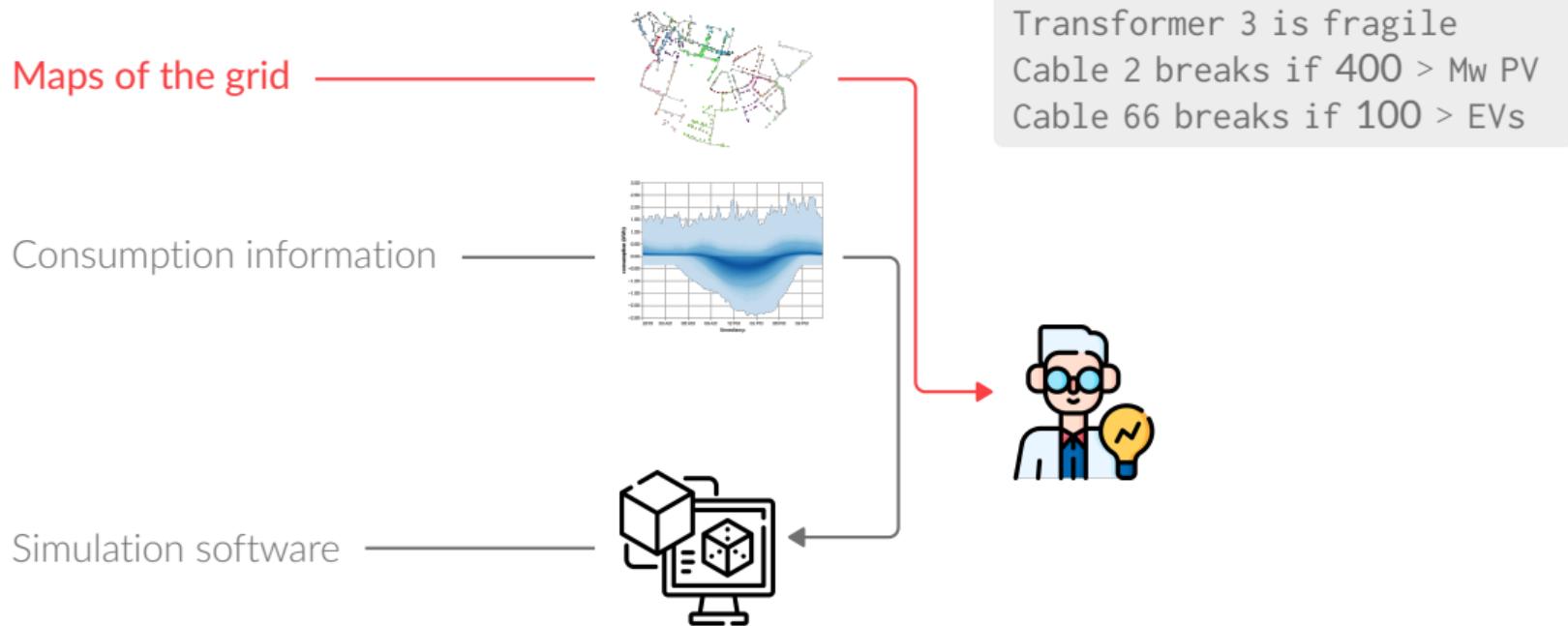
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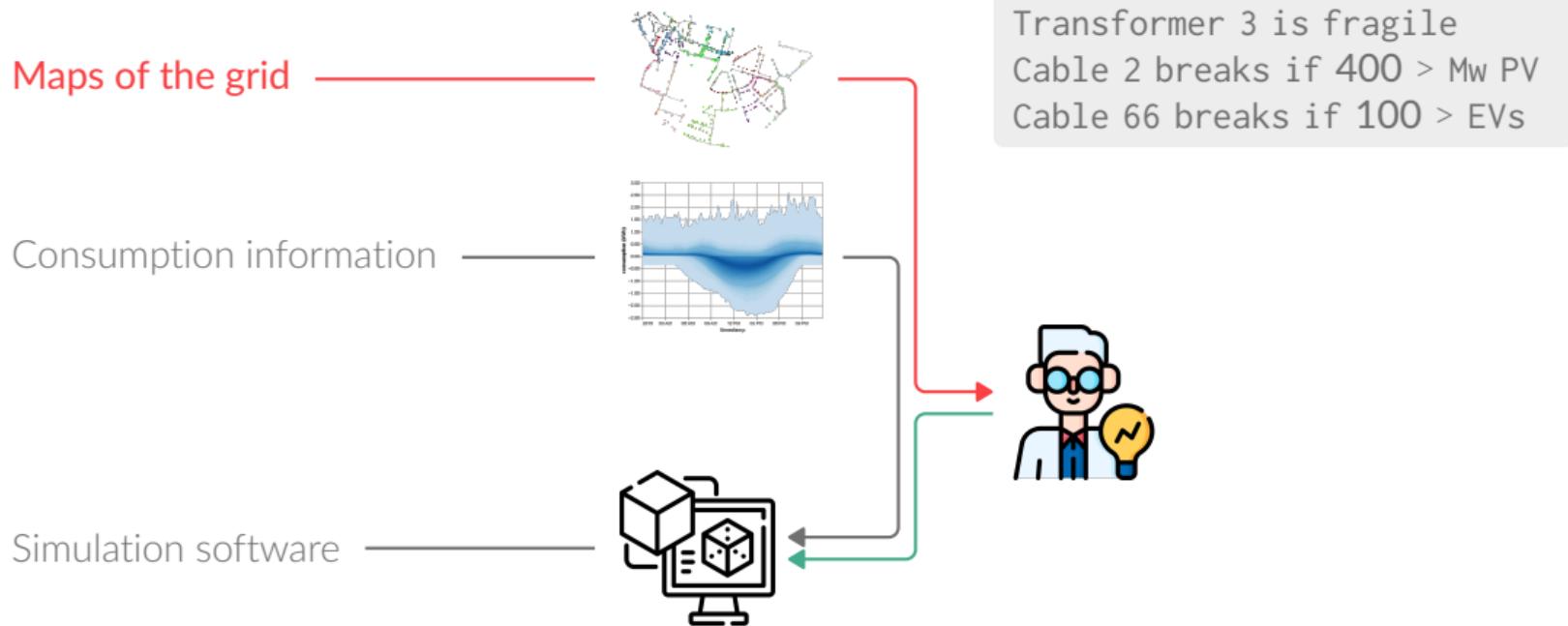
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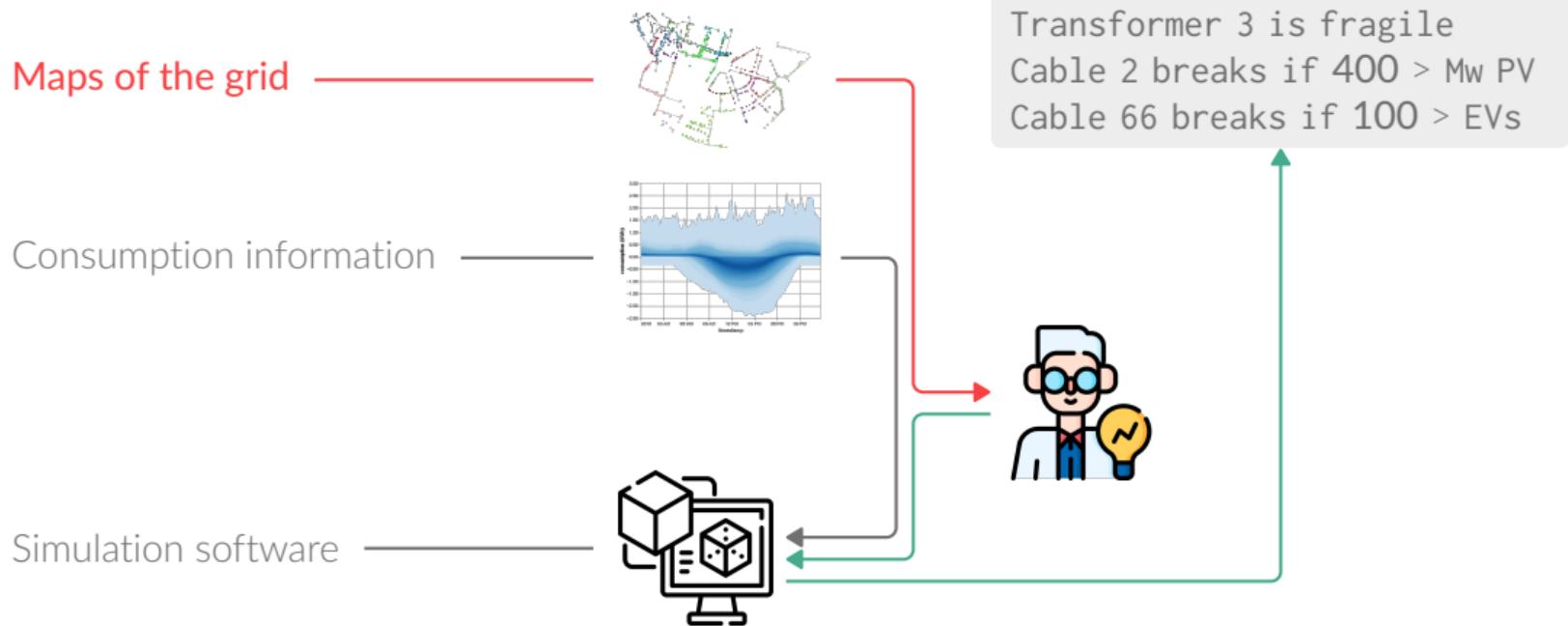
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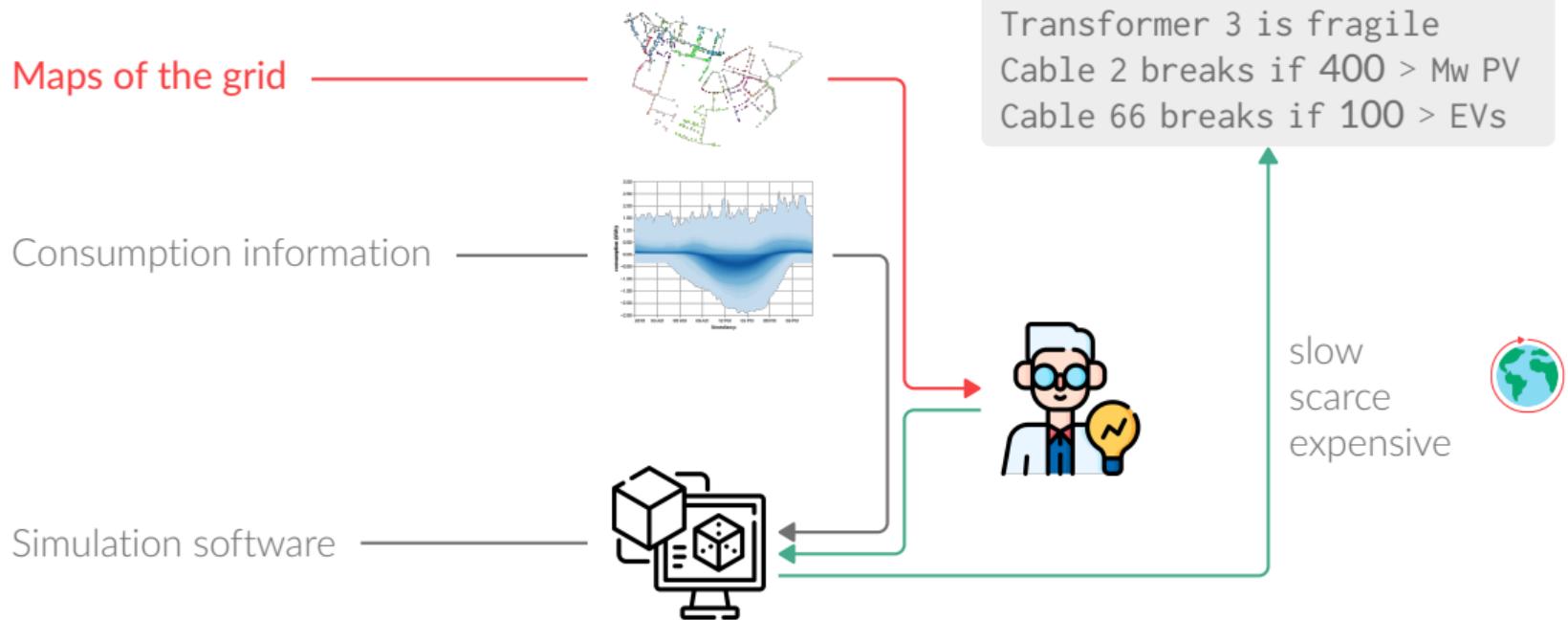
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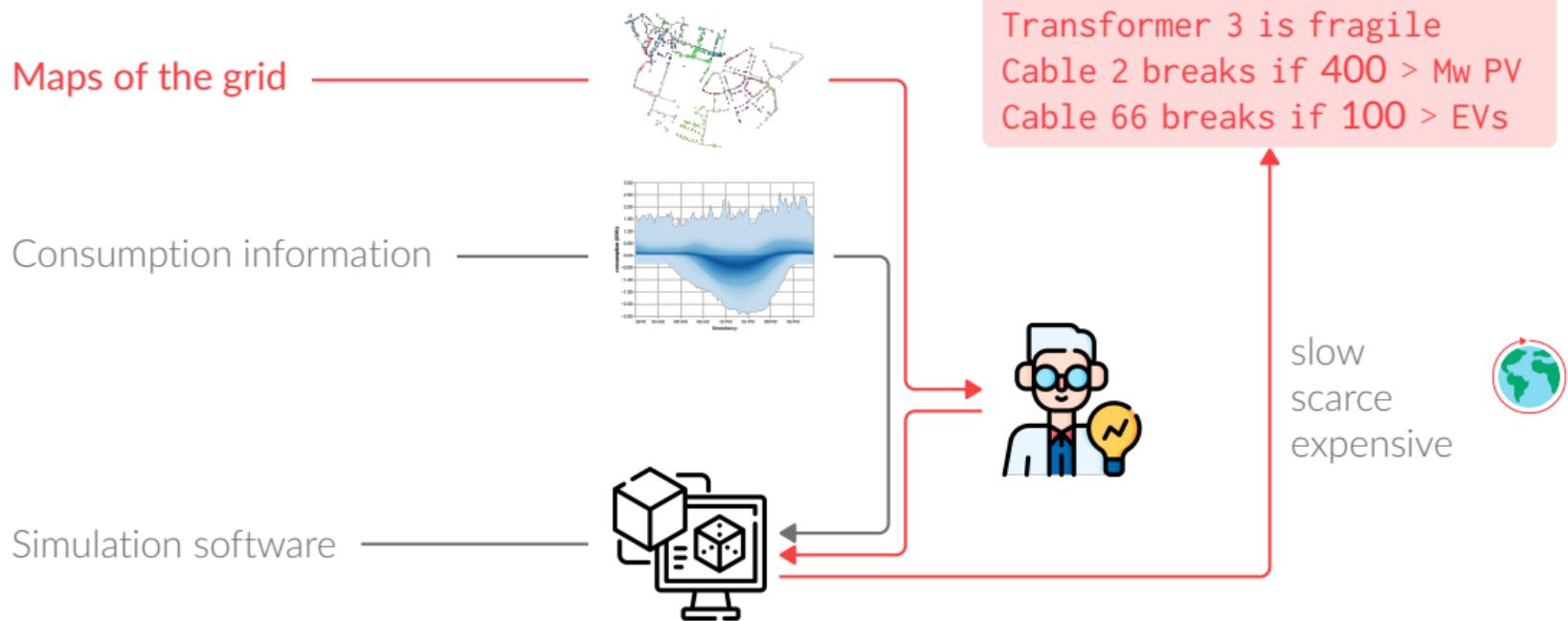
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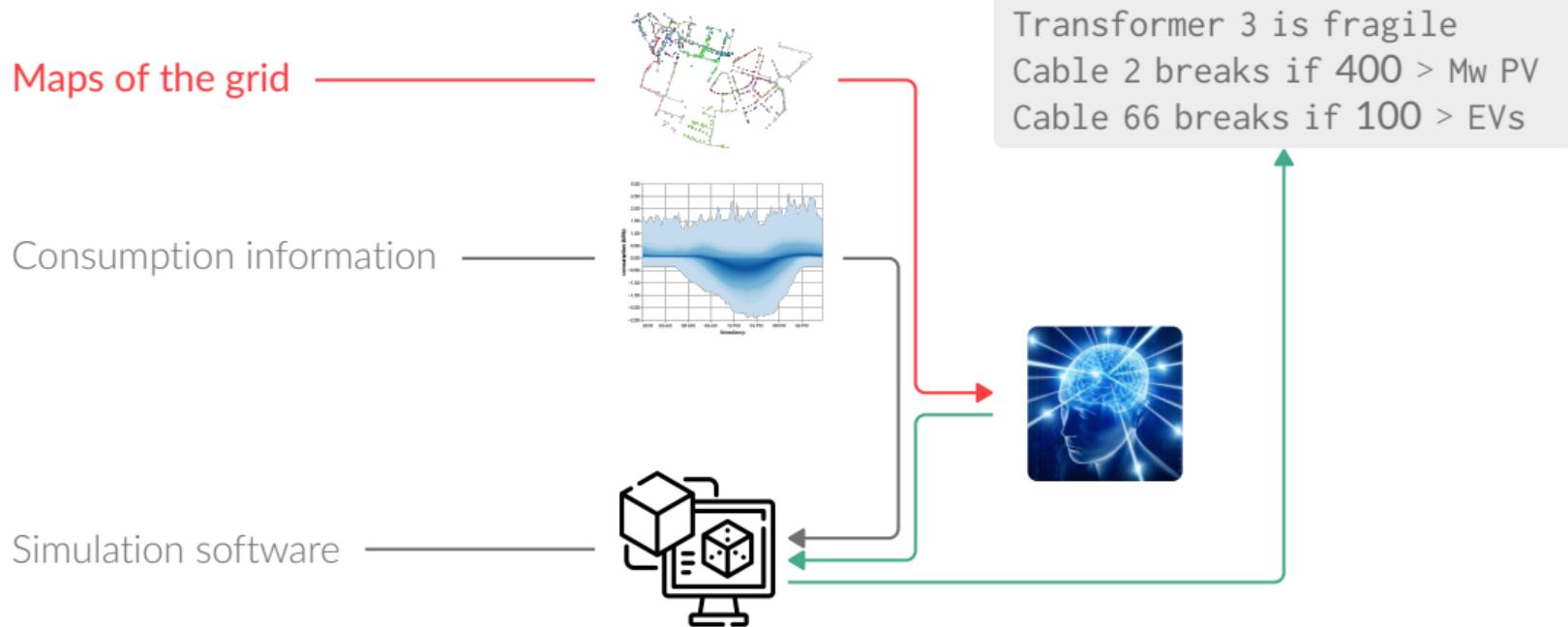
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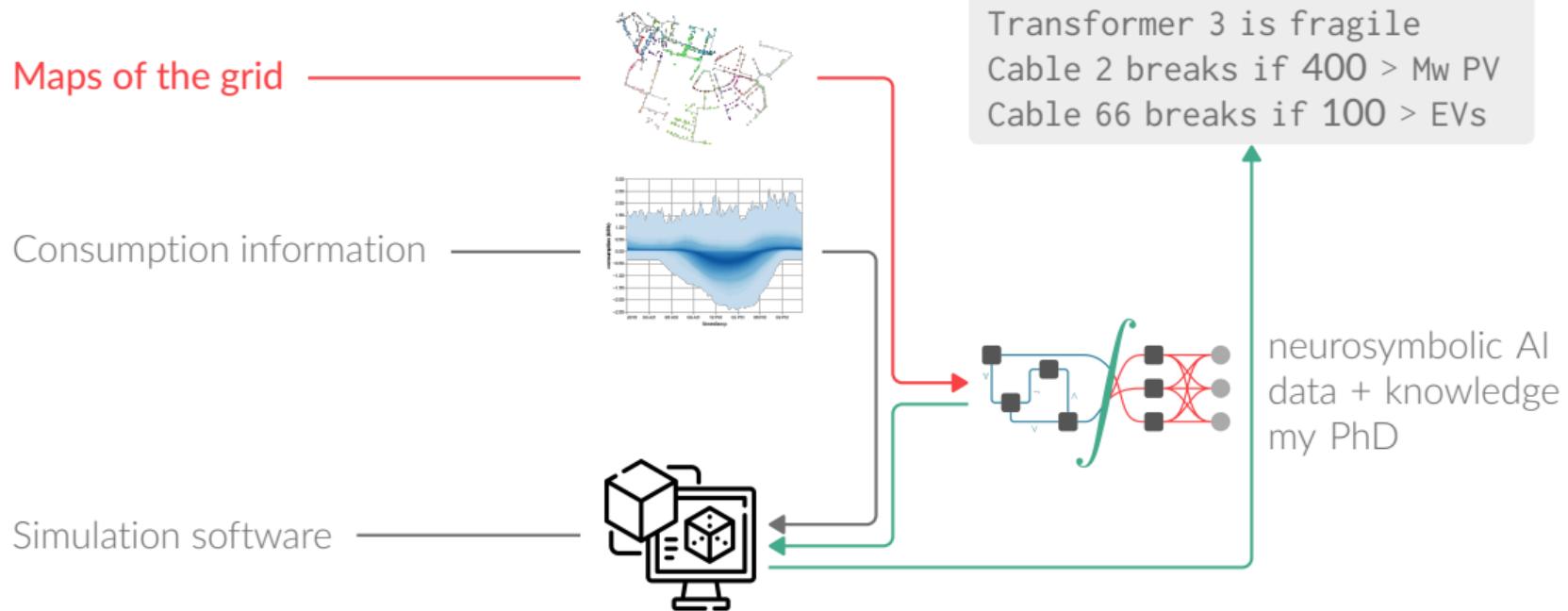
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Neurosymbolic AI experts could tell us where to modernise



Neurosymbolic AI experts could tell us where to modernise



Neurosymbolic AI could automate the experts

Experts use **data** and **knowledge** to correct grid maps

Neurosymbolic AI could automate the experts

Experts use **data** and **knowledge** to correct grid maps

Neurosymbolic AI = **data** + **knowledge**

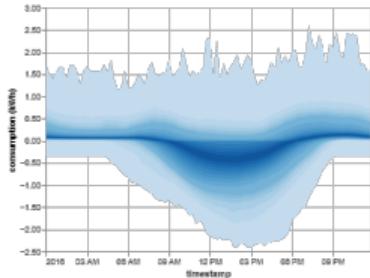
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Maps of the grid

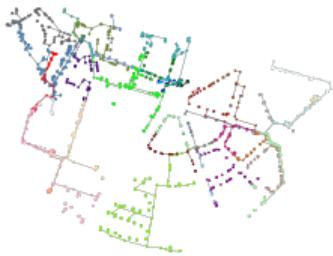


Consumption data

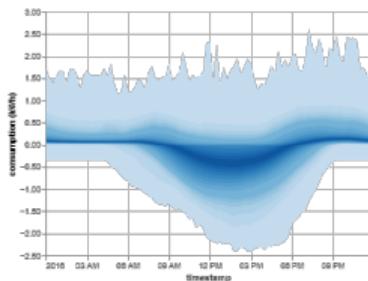
Neurosymbolic AI could automate the experts

Experts use **data** and **knowledge** to correct grid maps

Neurosymbolic AI = **data** + **knowledge**



Maps of the grid



Consumption data

Cables do not collide
Connections are short
Similar voltage levels
for same connections

Expert knowledge

Neurosymbolic AI could automate the experts
but has three major challenges

Challenge 1: chaos

Many approaches and no understanding

Neurosymbolic AI could automate the experts
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Challenge 1: chaos

Many approaches and no understanding

Challenge 2: continuous variables

No approaches handle continuous variables

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Many approaches do not scale to large problems

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- 1 Unifying neurosymbolic AI by abstracting its core concepts
- 2 Scaling neurosymbolic AI to larger problems
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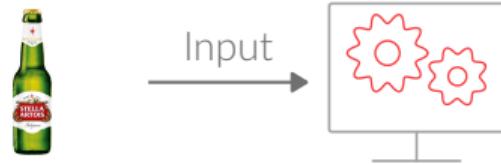
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What is **neurosymbolic** AI and why do we need it?

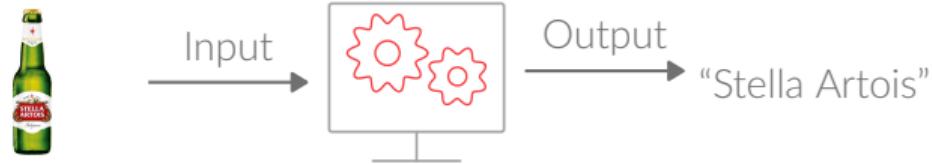
What is **neural** AI?



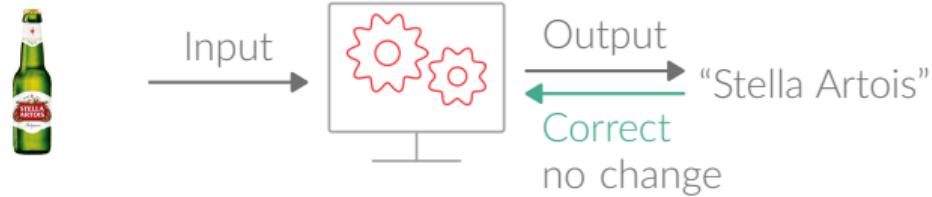
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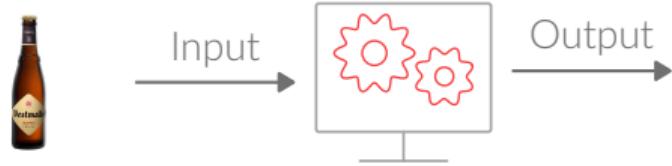
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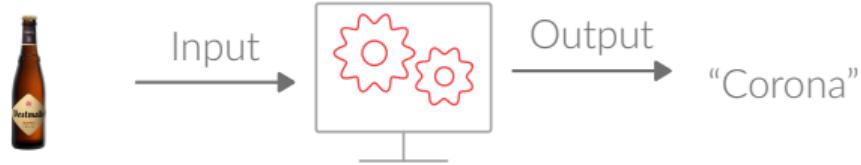
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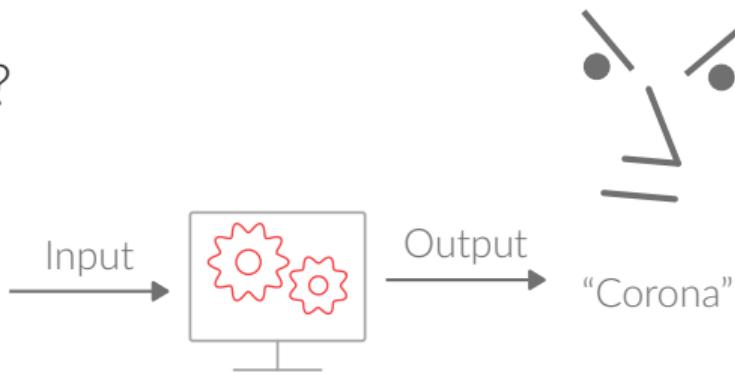
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What is **neural** AI?



What is **neural** AI?



What is **neural** AI?



Input



Output

Incorrect
change

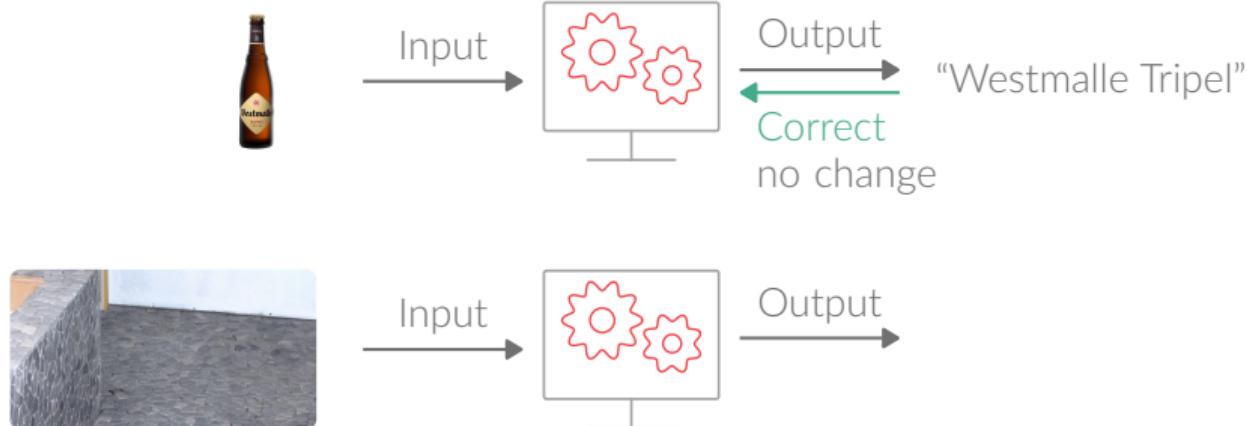


"Corona"

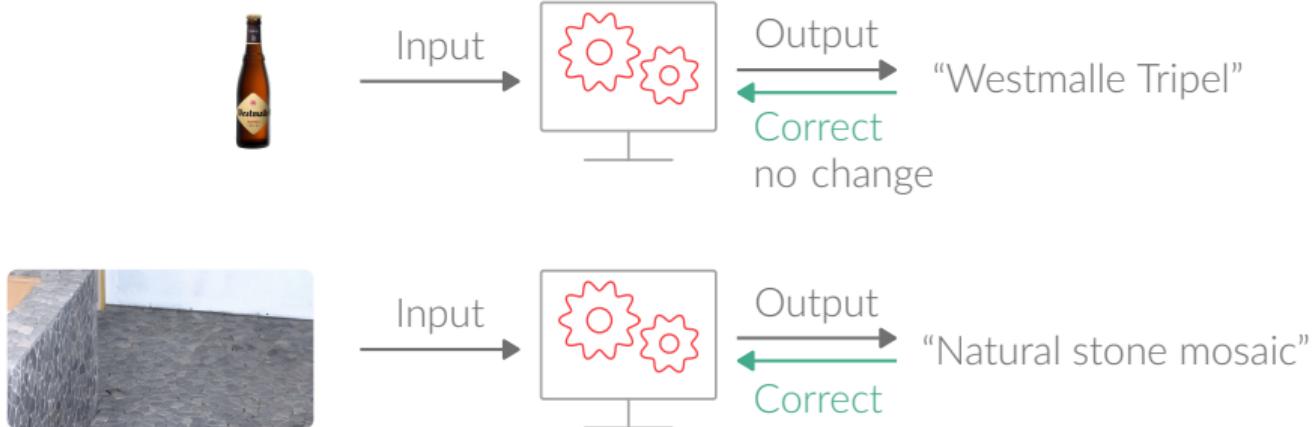
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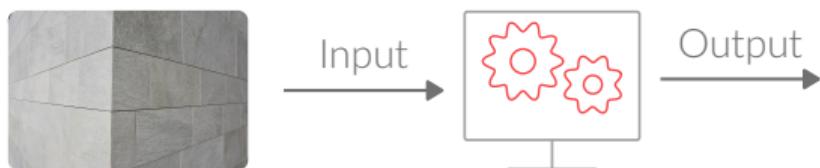
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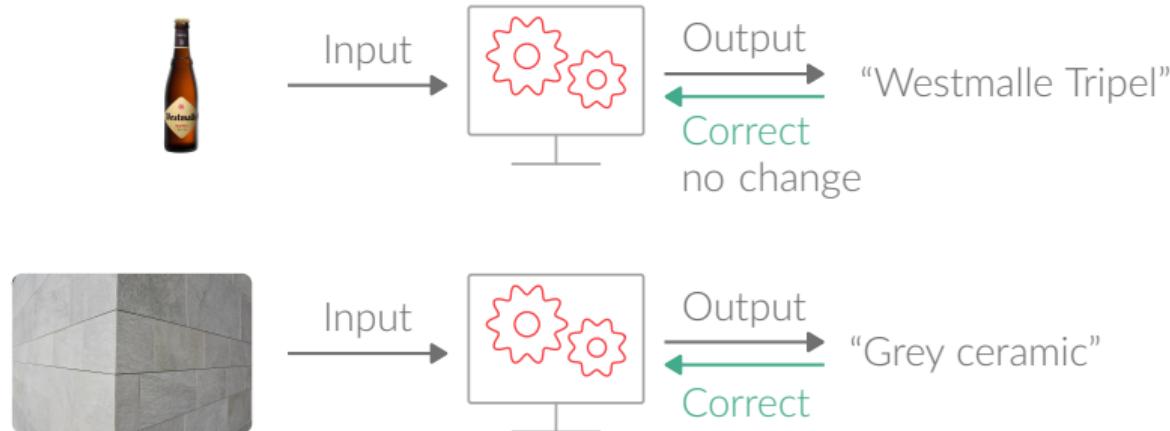
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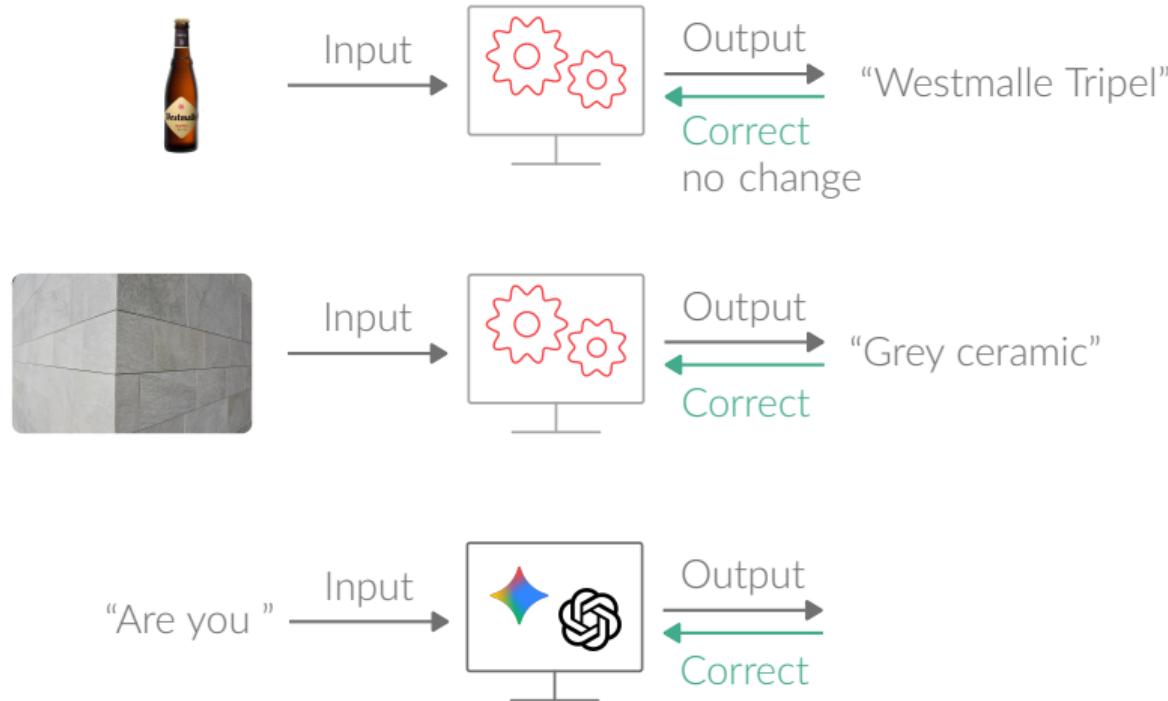
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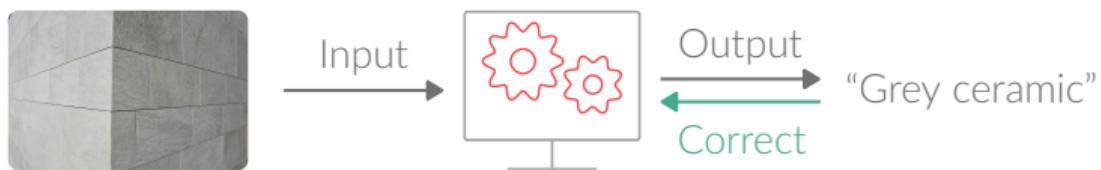
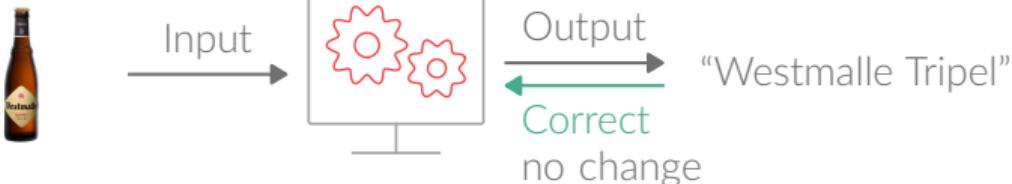
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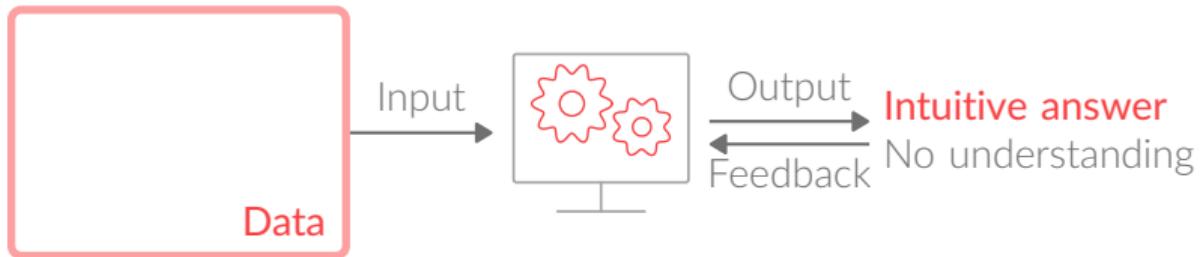
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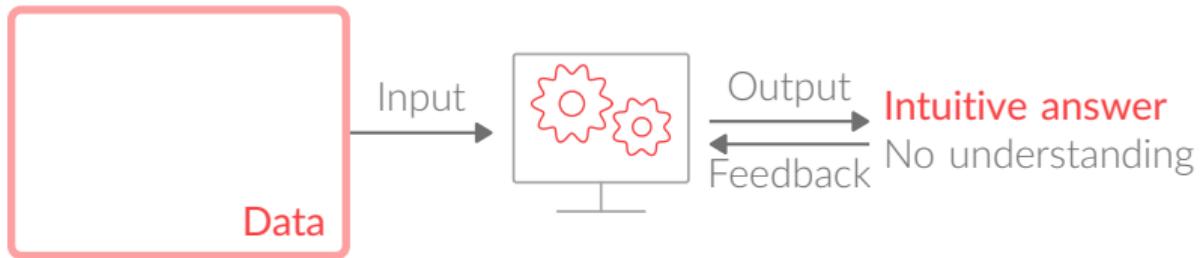
What is **neural** AI?



How to abstract **neural** AI?



How to abstract **neural** AI?



What is **symbolic** AI?

If the bottle is not green,
then it is not Stella

If it is not Stella,
then it is Westmalle

The bottle is not green

What is **symbolic** AI?

If the bottle is not green,
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Background
Knowledge



What is **symbolic** AI?

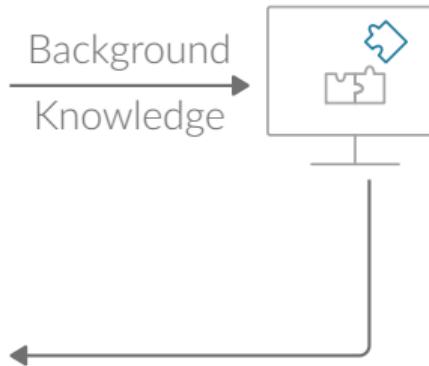
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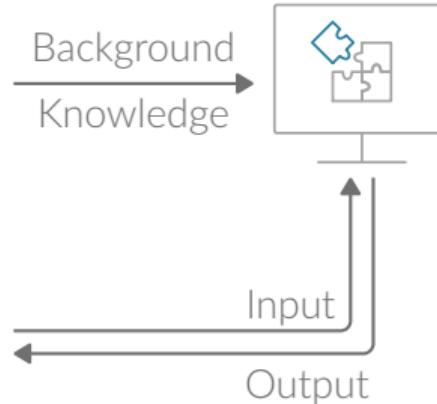
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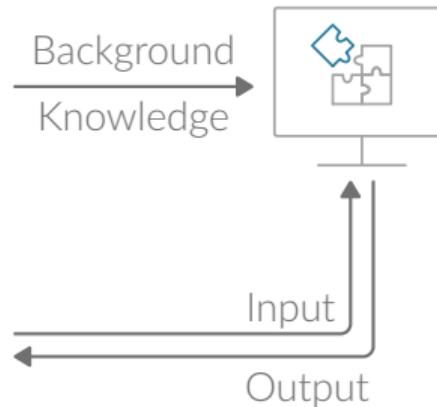
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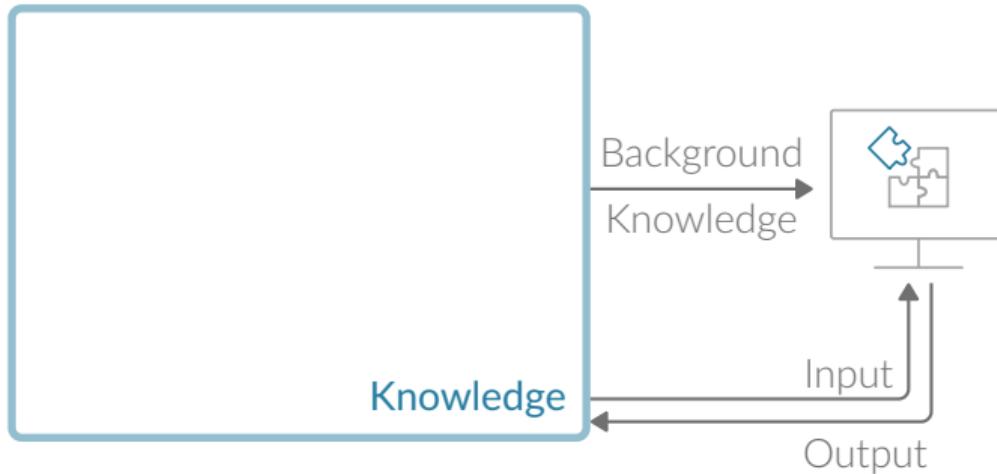
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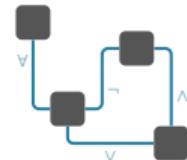
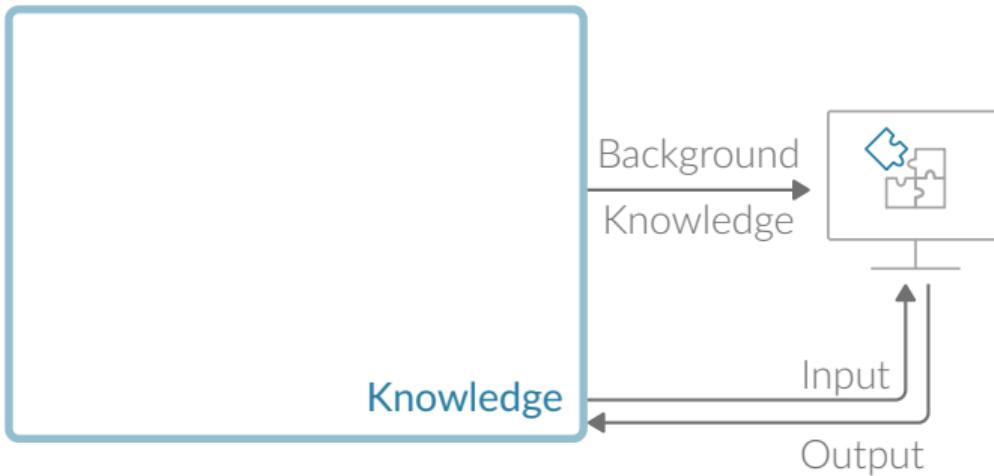
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How to abstract **symbolic** AI?

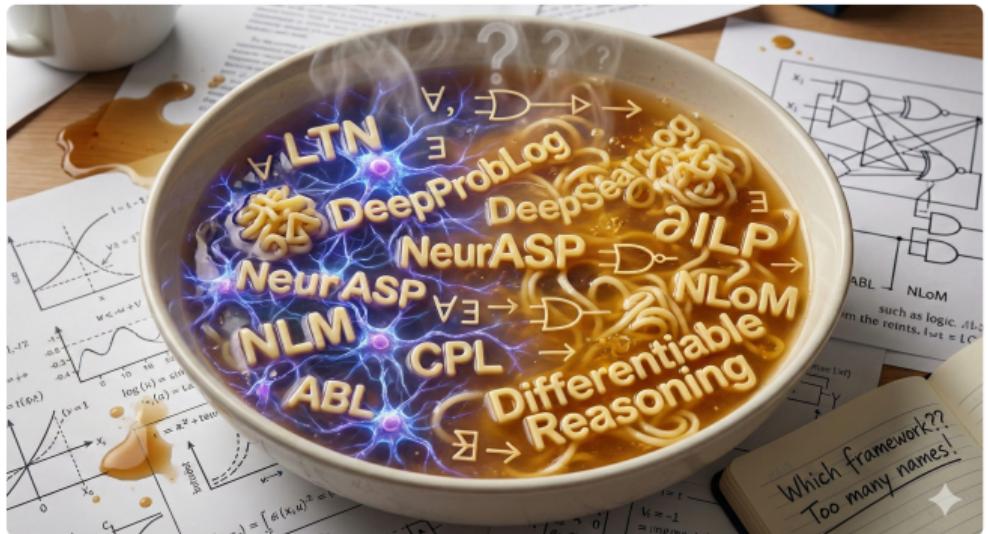


How to abstract **symbolic** AI?



Why do we need to abstract things?

Too many different systems!
the field is chaotic

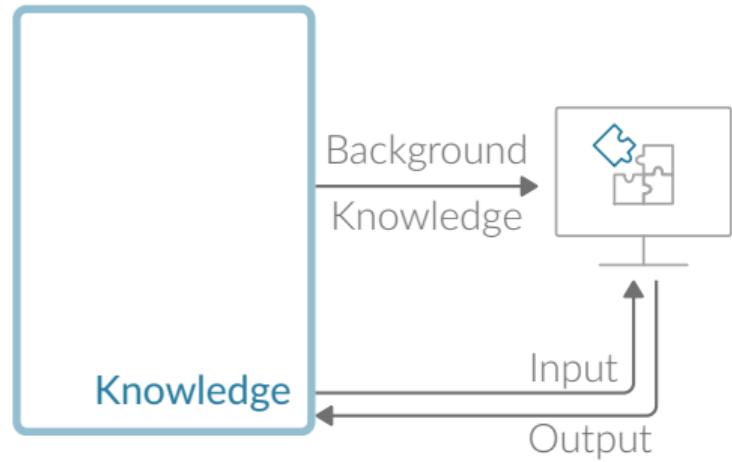


Which framework??
Too many names!

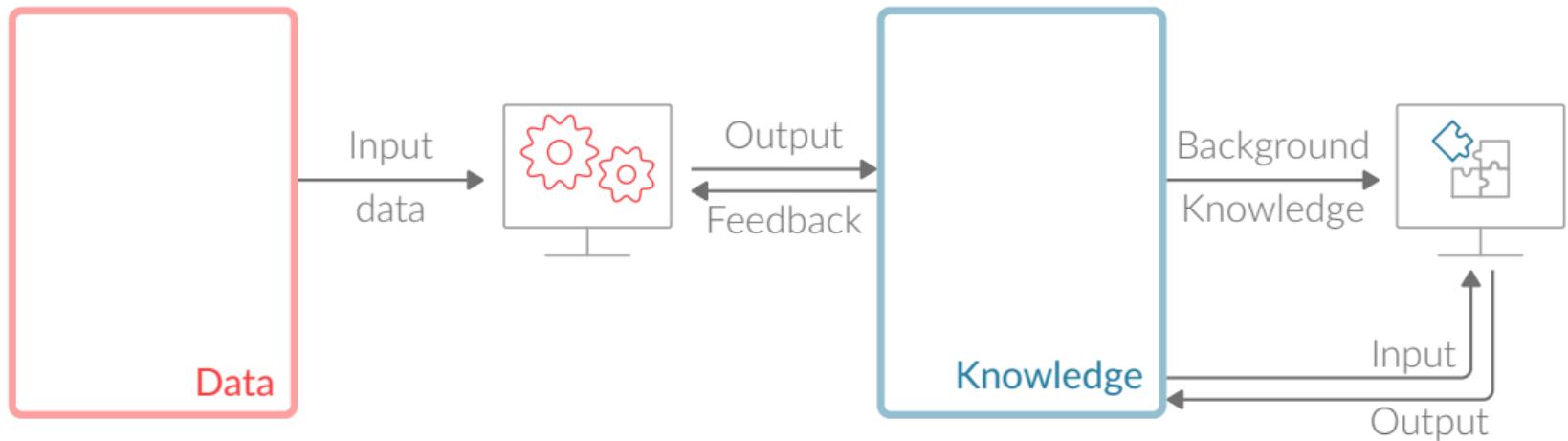
How do we now describe all of neurosymbolic AI?



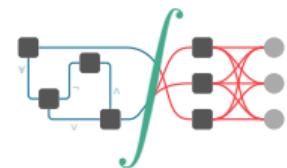
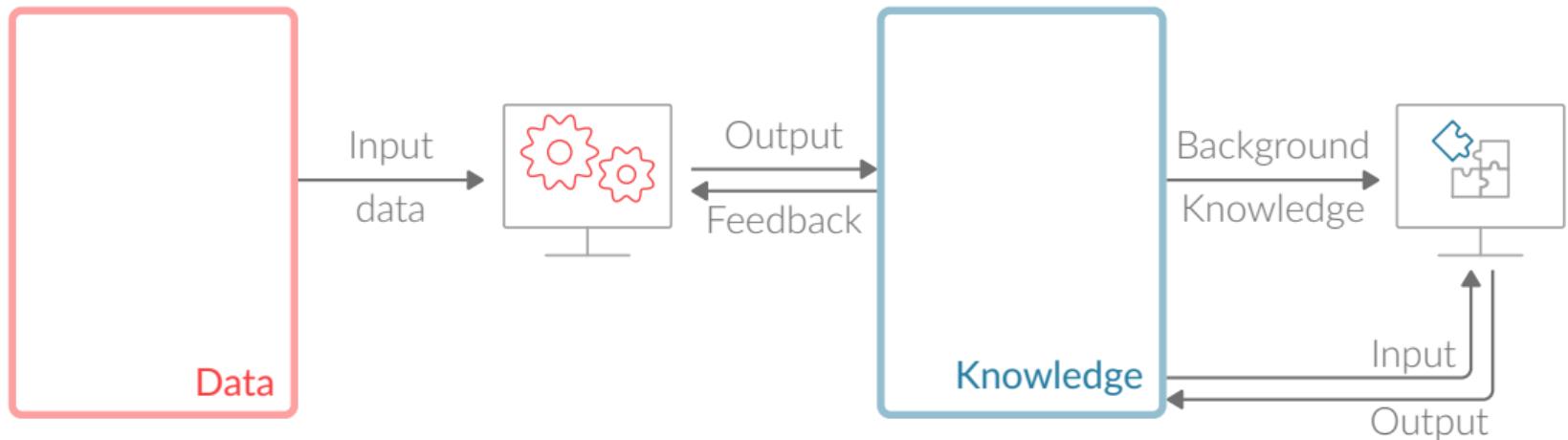
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How do we now describe all of neurosymbolic AI?



How do we now describe all of neurosymbolic AI?



So what does this unification give us?

Foundation

Mathematical foundation for future research
so researchers can understand each other

So what does this unification give us?

Foundation Mathematical foundation for future research
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Communication Abstract and intuitive concepts
so researchers can communicate their ideas better

So what does this unification give us?

Foundation Mathematical foundation for future research so researchers can understand each other

Communication Abstract and intuitive concepts so researchers can communicate their ideas better

Applications Easier to understand and apply so practitioners can build real-world solutions

- 1 Unifying neurosymbolic AI by abstracting its core concepts
- 2 Scaling neurosymbolic AI to larger problems
- 3 Scaling neurosymbolic AI to dynamic problems

What kind of problems again?

The bad

We don't have correct maps of the energy grid because of bad annotations, missing information, etc.

What kind of problems again?

The bad

We don't have correct maps of the energy grid because of bad annotations, missing information, etc.

Good?

Experts can correct the maps by looking at data and using their knowledge

What kind of problems again?

The bad

We don't have correct maps of the energy grid because of bad annotations, missing information, etc.

Good?

Experts can correct the maps by looking at data and using their knowledge

No, bad again

Experts are expensive and too slow because they are scarce and can't look at all maps



Assigning correct transformers to houses



Each house needs exactly one transformer
to provide electricity

Assigning correct transformers to houses



Each house needs exactly one transformer
to provide electricity



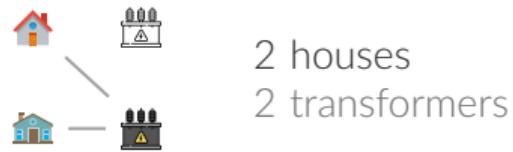
Knowledge
Short connections

The assignment needs to be correct
and satisfy expert knowledge

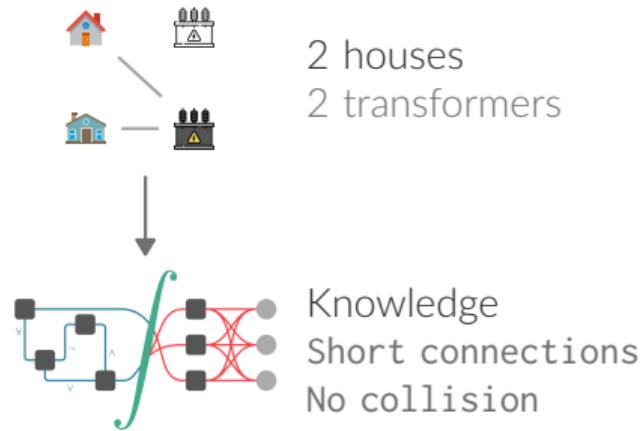


No collision

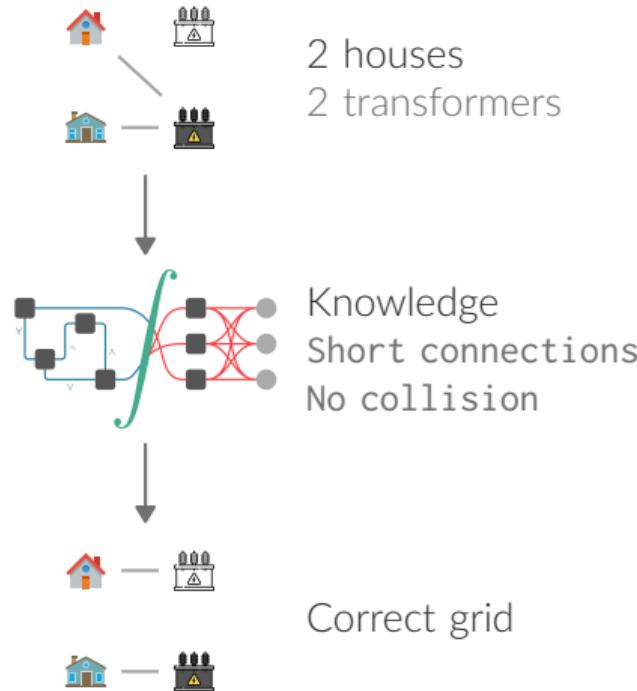
What do we mean with scaling and why do we need it?



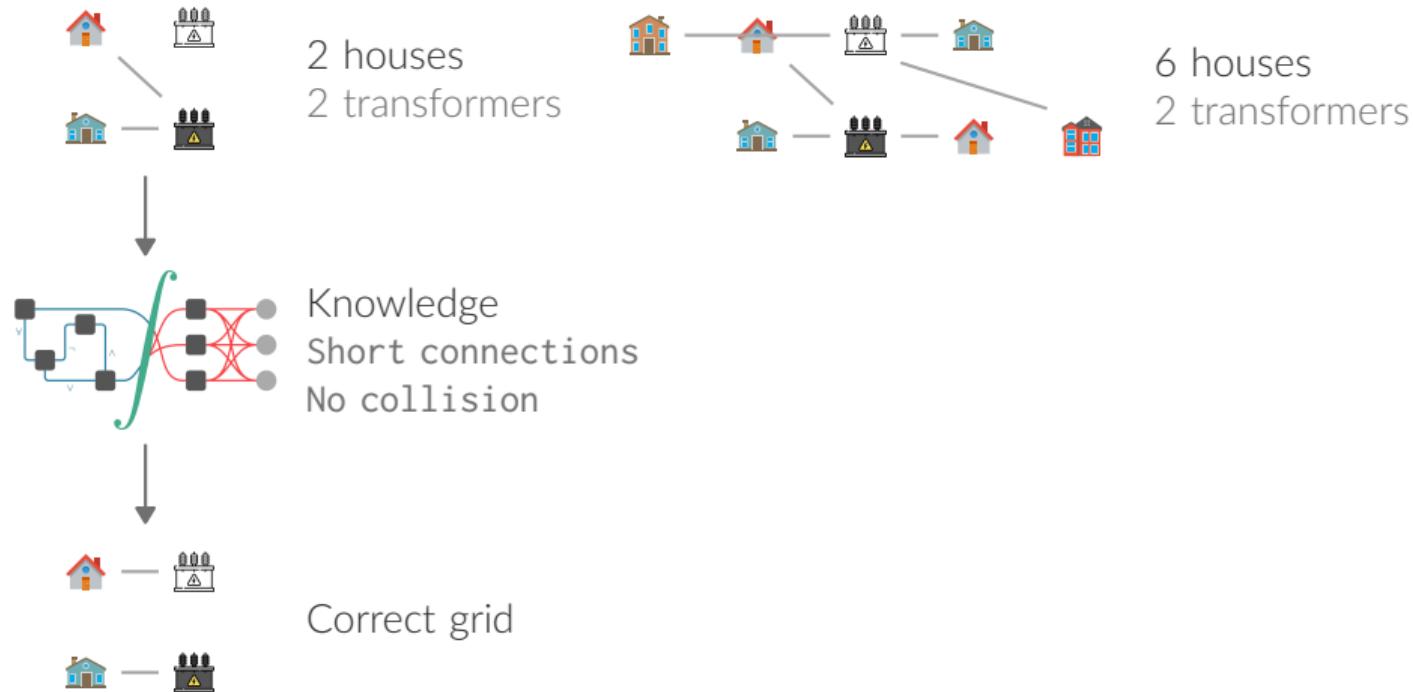
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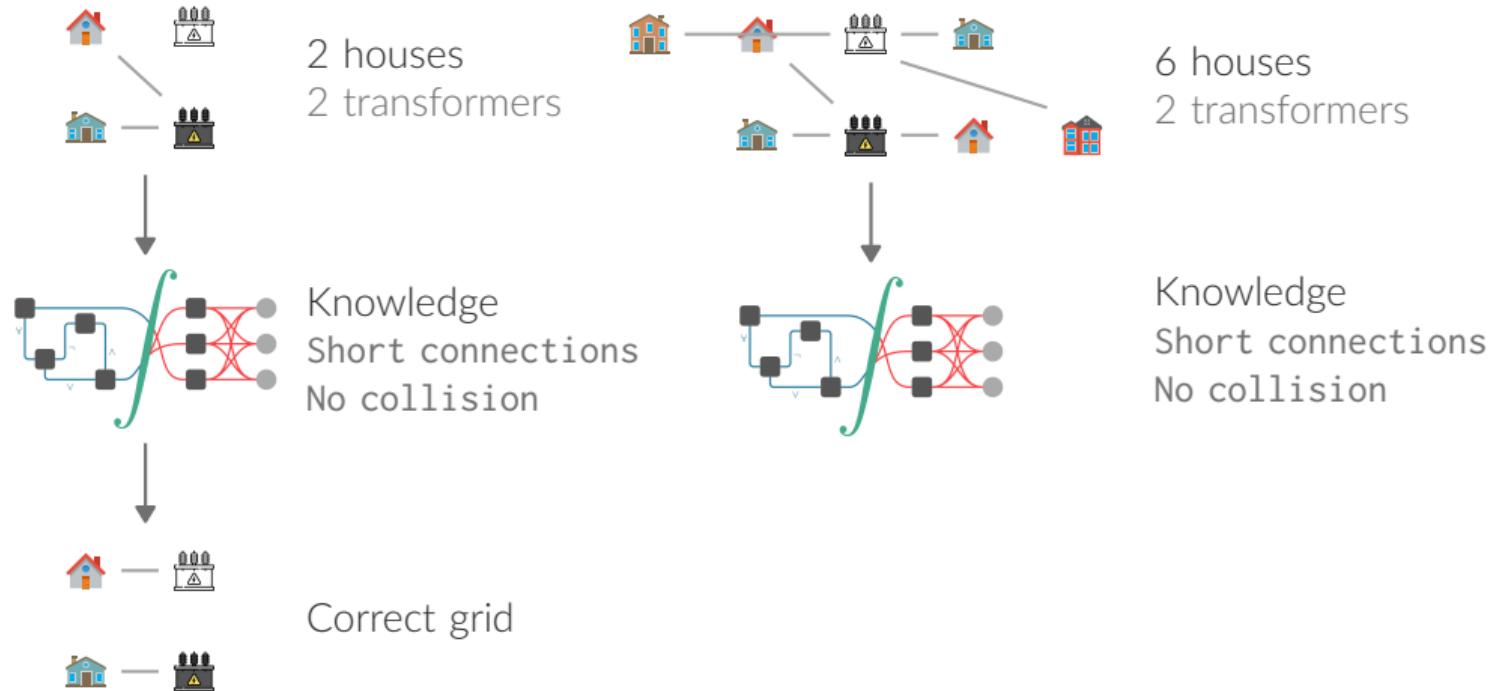
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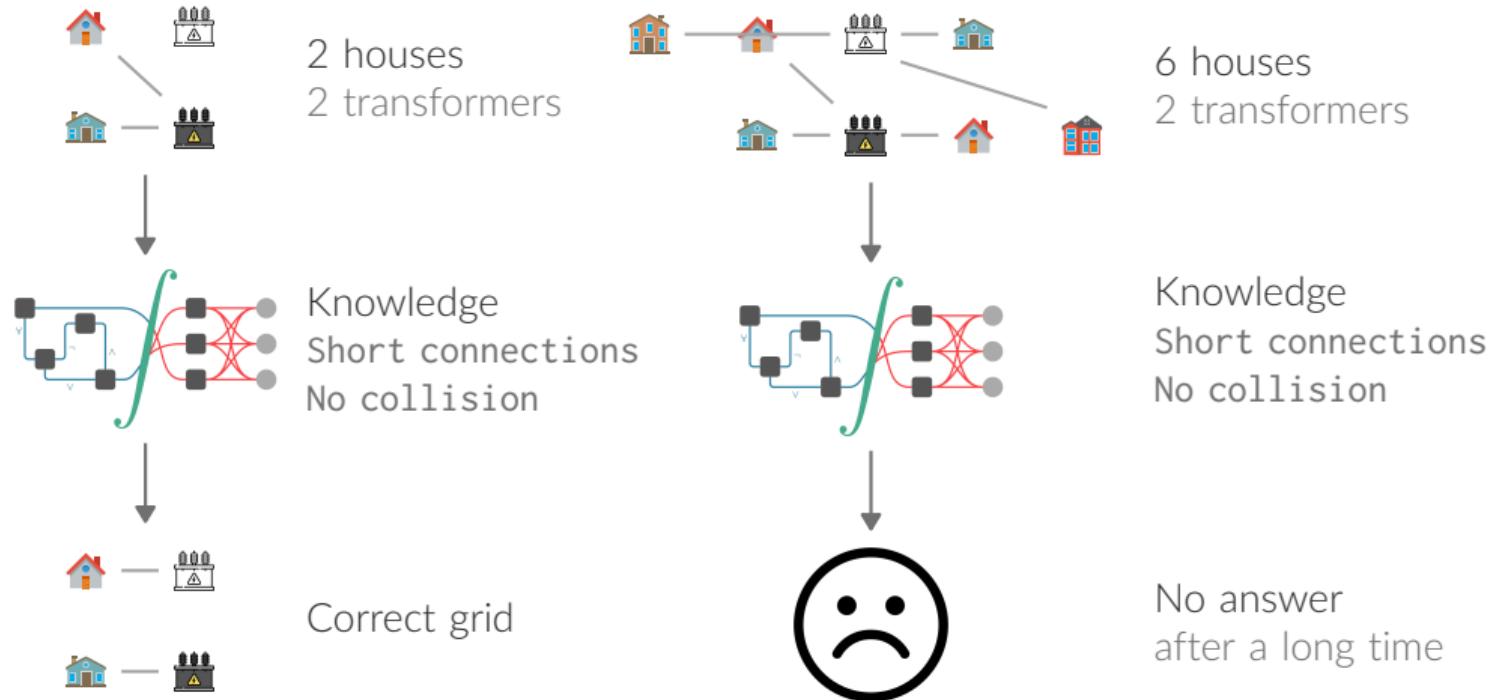
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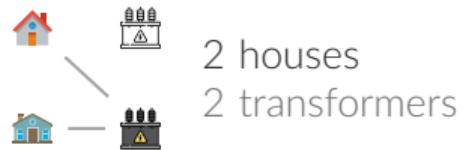
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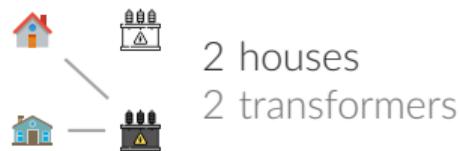
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Why do things not scale?

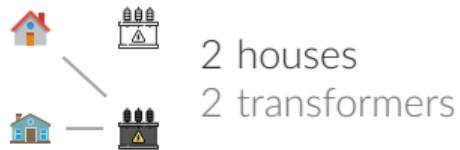


Why do things not scale?



How many possible grids?

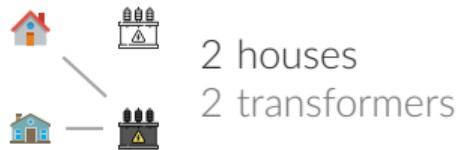
Why do things not scale?



How many possible grids?

Each house has 2 choices

Why do things not scale?



How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 = 4$ possible grids

Why do things not scale?



2 houses



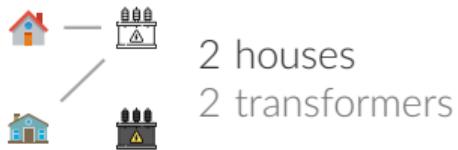
2 transformers

How many possible grids?

Each house has 2 choices

→ $2 \times 2 = 4$ possible grids

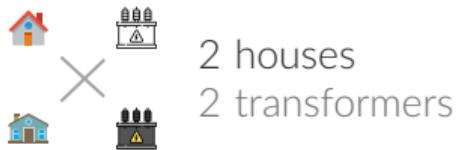
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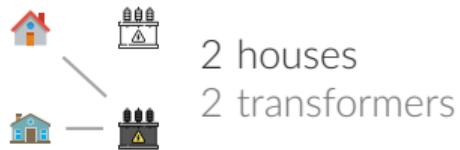


2 houses
2 transformers

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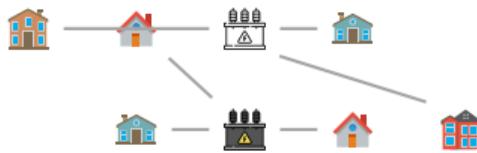
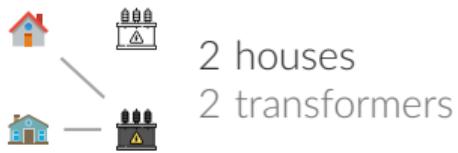
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 $\rightarrow 2 \times 2 = 4$ possible grids

Why do things not scale?

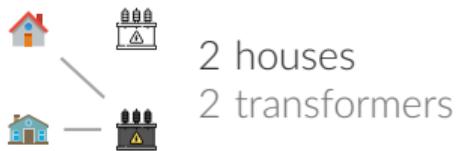


6 houses
2 transformers

How many possible grids?

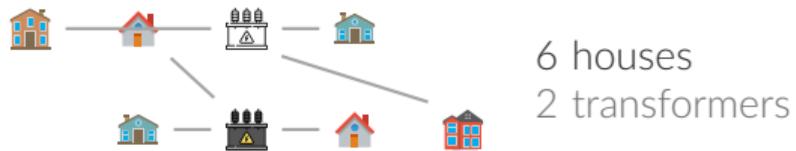
Each house has 2 choices
 $\rightarrow 2 \times 2 = 4$ possible grids

Why do things not scale?



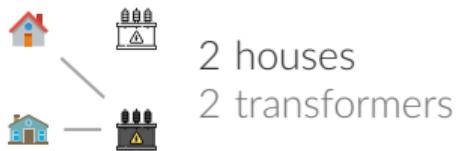
How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 = 4$ possible grids



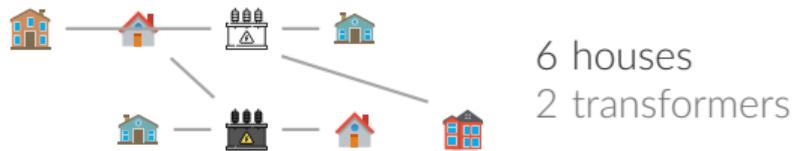
How many possible grids?

Why do things not scale?



How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 = 4$ possible grids



How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$ possible grids

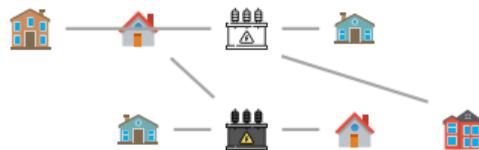
Why do things not scale?



2 houses
2 transformers

How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 = 4$ possible grids



6 houses
2 transformers

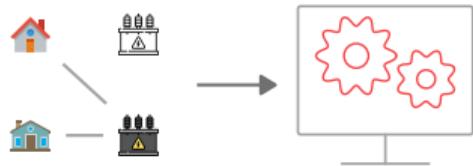
How many possible grids?

Each house has 2 choices
 $\rightarrow 2 \times 2 \times 2 \times 2 \times 2 \times 2 = 64$ possible grids

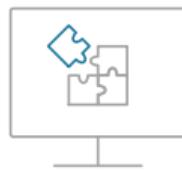
Problem

The number of possibilities explodes

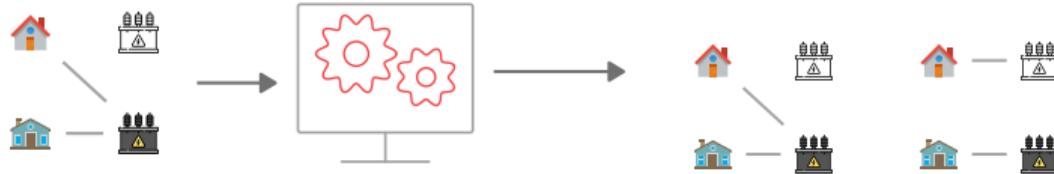
Learning to look at limited options scales



Knowledge
Short connections
No collision



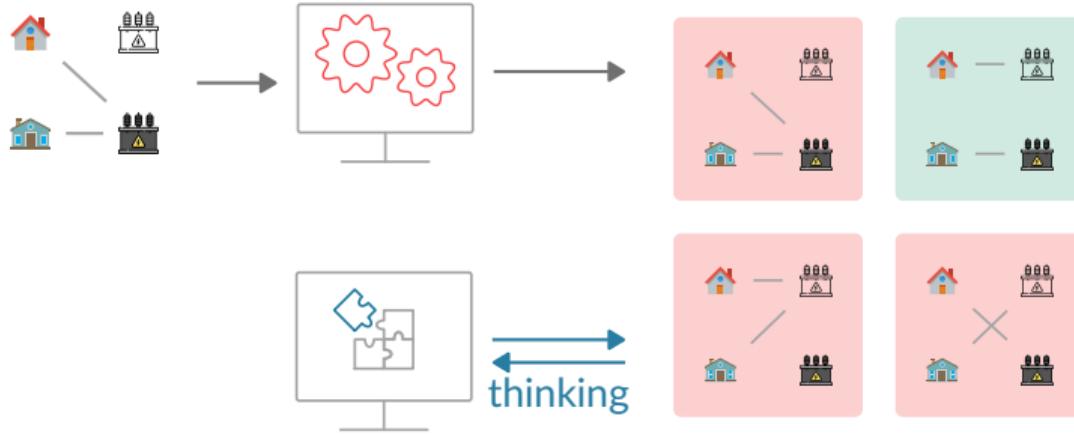
Learning to look at limited options scales



Knowledge
Short connections
No collision

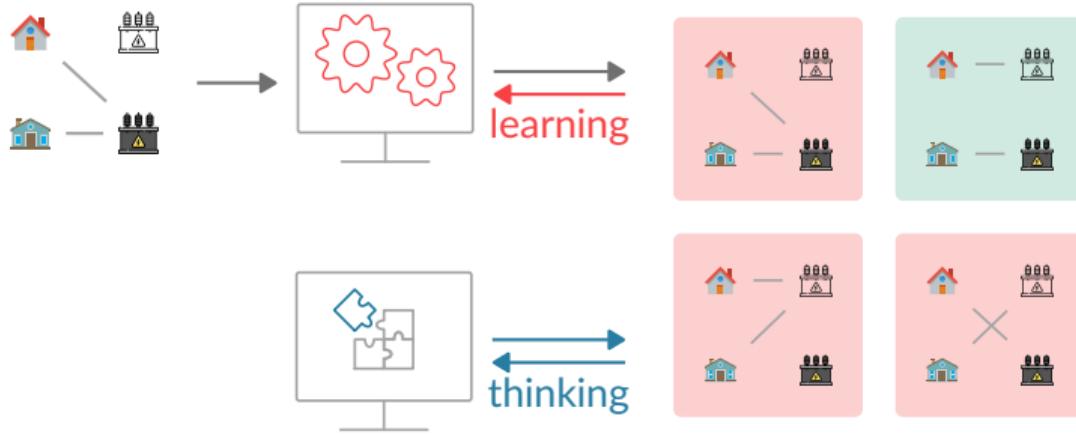


Learning to look at limited options scales



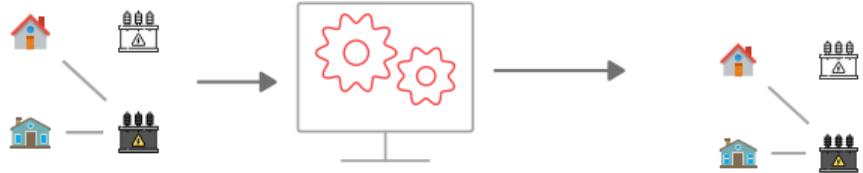
Knowledge
Short connections
No collision

Learning to look at limited options scales

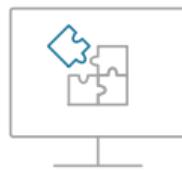


Knowledge
Short connections
No collision

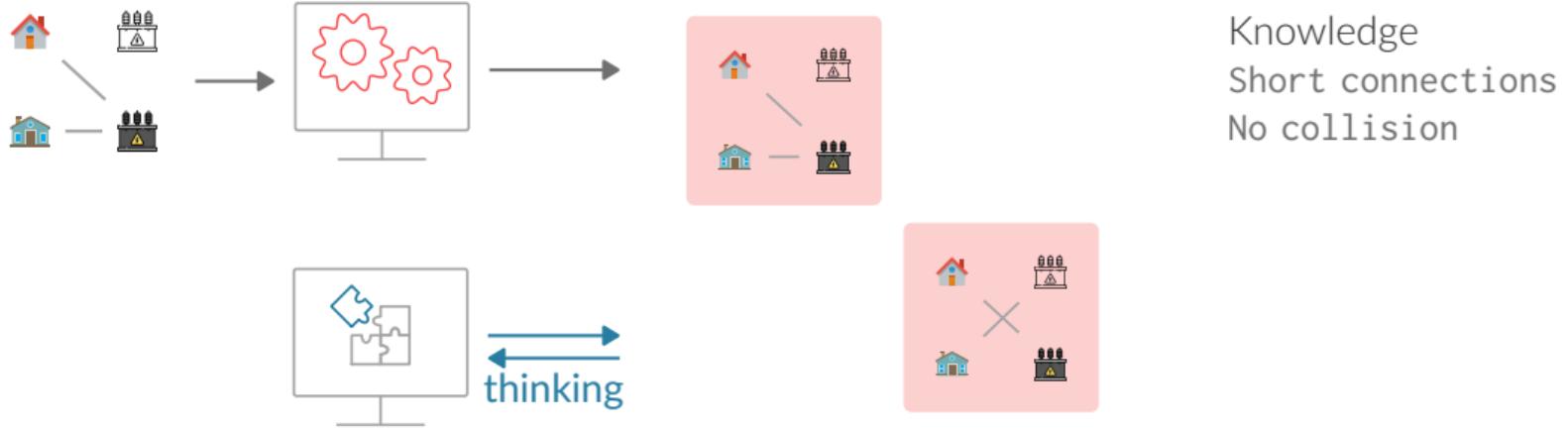
Learning to look at limited options scales



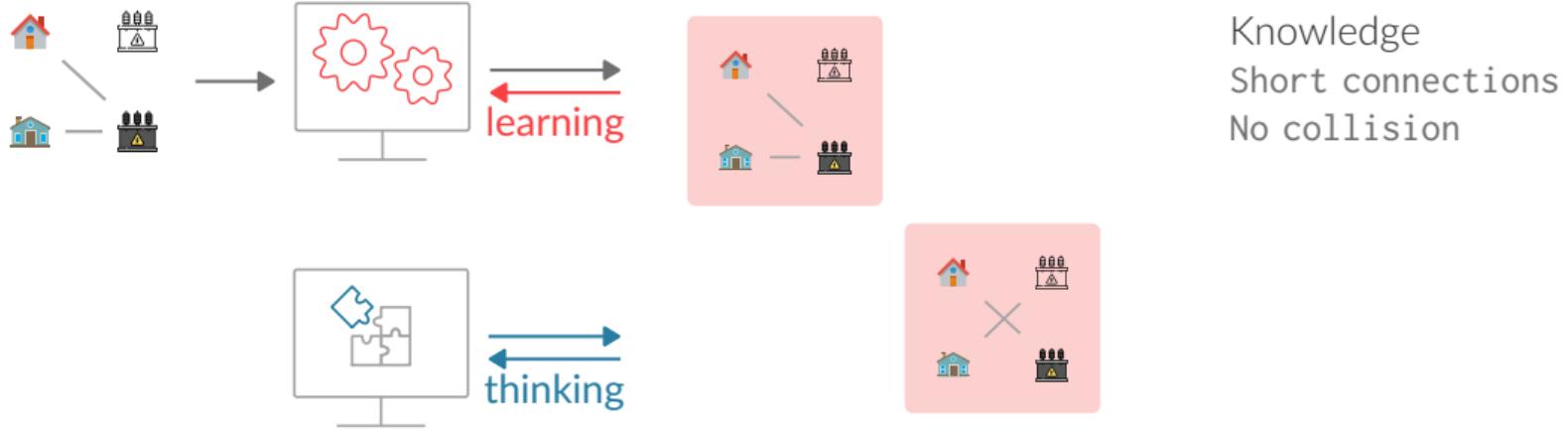
Knowledge
Short connections
No collision



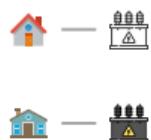
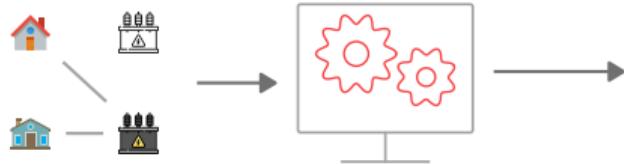
Learning to look at limited options scales



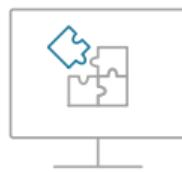
Learning to look at limited options scales



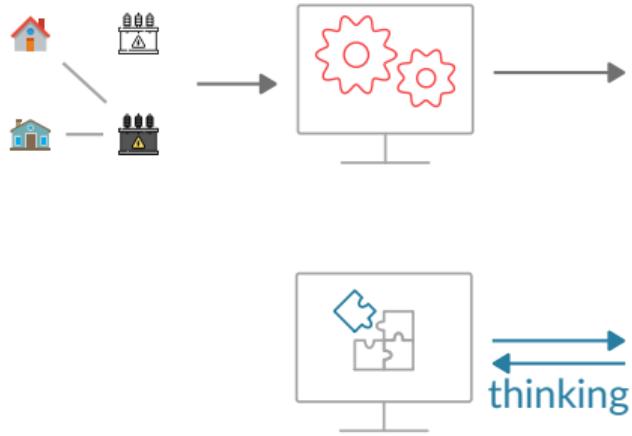
Learning to look at limited options scales



Knowledge
Short connections
No collision

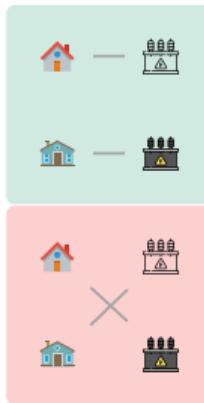
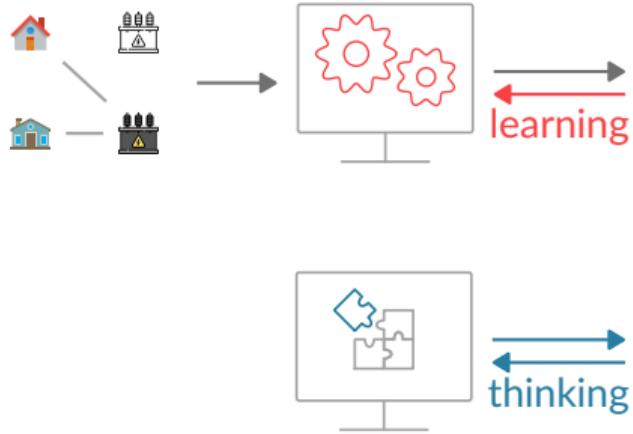


Learning to look at limited options scales



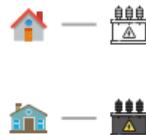
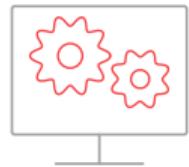
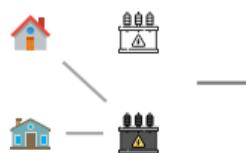
Knowledge
Short connections
No collision

Learning to look at limited options scales

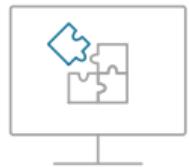


Knowledge
Short connections
No collision

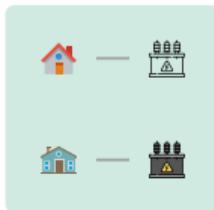
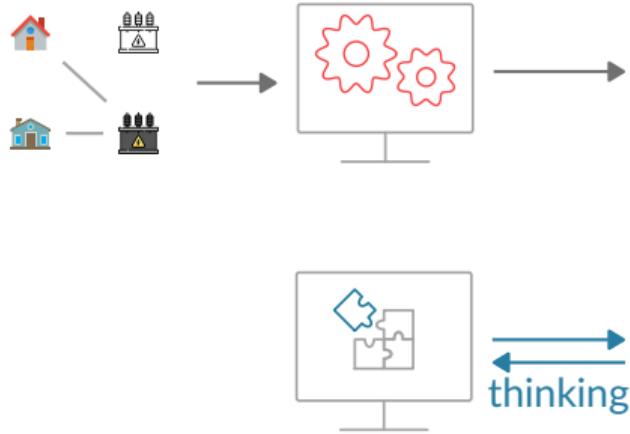
Learning to look at limited options scales



Knowledge
Short connections
No collision

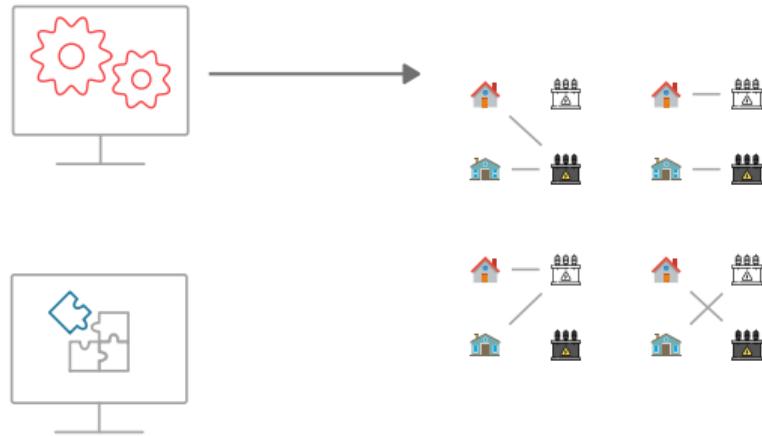


Learning to look at limited options scales

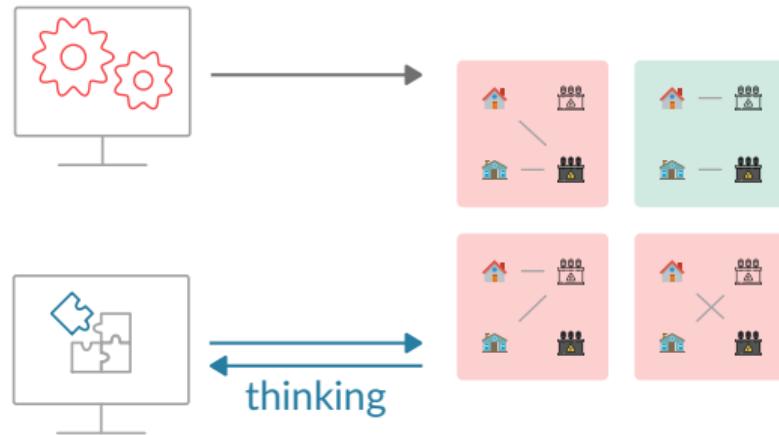


Knowledge
Short connections
No collision

Taking limited options complicates learning

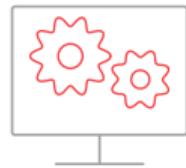


Taking limited options complicates learning



Taking limited options complicates learning

All options
good direction



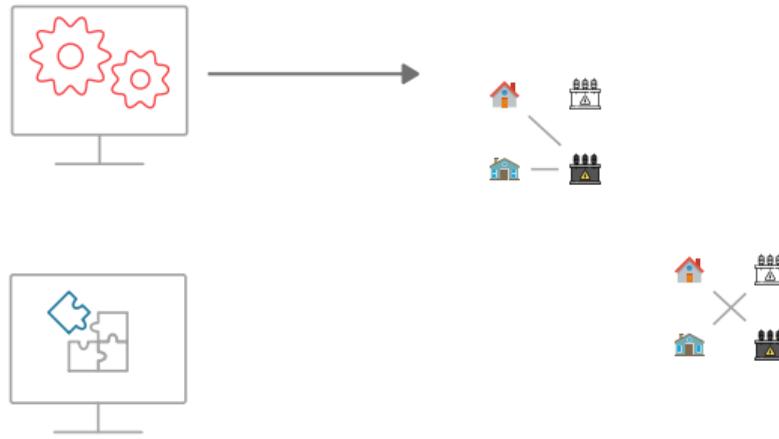
learning



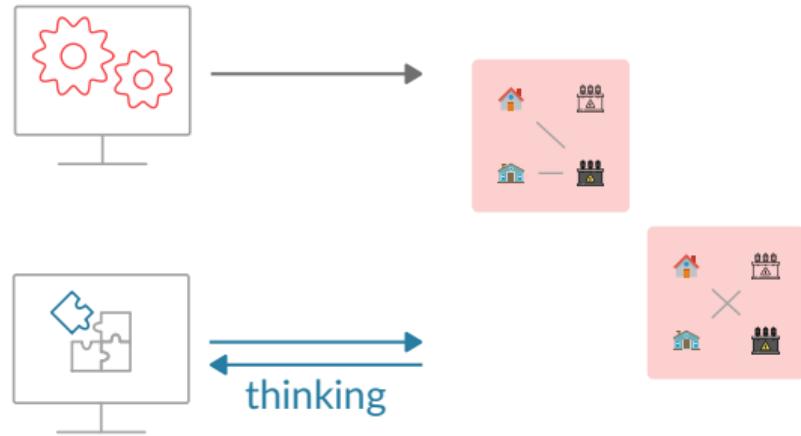
thinking



Taking limited options complicates learning

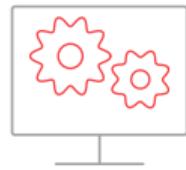


Taking limited options complicates learning



Taking limited options complicates learning

Some options
worse direction



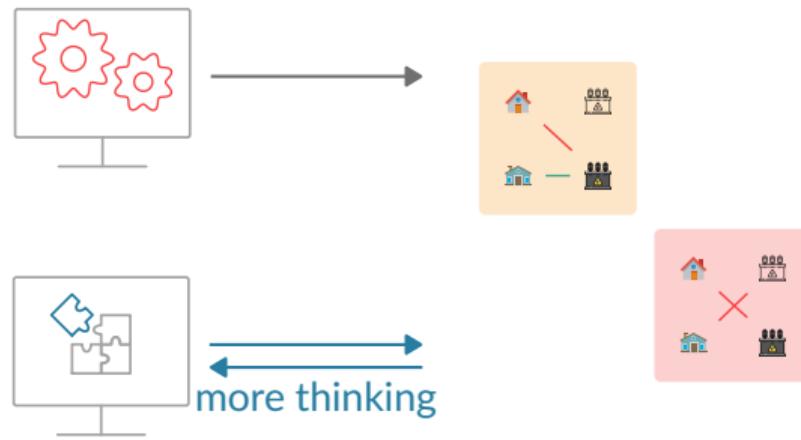
learning



thinking

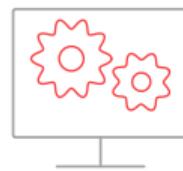


Taking limited options complicates learning unless we add more thinking

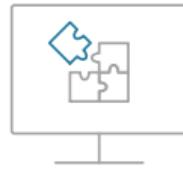


Taking limited options complicates learning unless we add more thinking

Some options
local information
better direction



learning



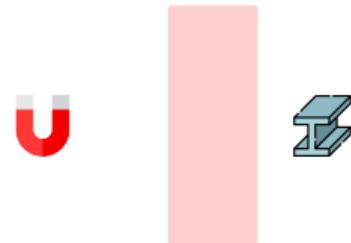
more thinking



- 1 Unifying neurosymbolic AI by abstracting its core concepts
- 2 Scaling neurosymbolic AI to larger problems
- 3 Scaling neurosymbolic AI to dynamic problems

What do we mean with dynamics?

Time step 0



Somewhere **here**
there is a rock

What do we mean with dynamics?

Time step 0



Could be [here](#)

What do we mean with dynamics?

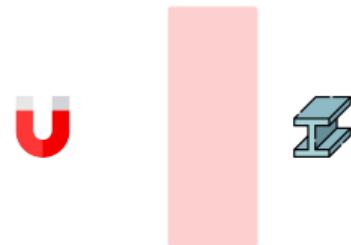
Time step 0



Could be **here**
or **there**

What do we mean with dynamics?

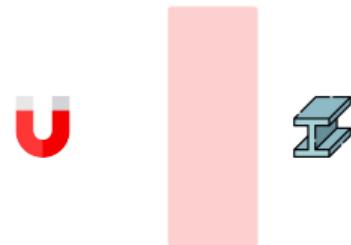
Time step 0



We don't know

What do we mean with dynamics?

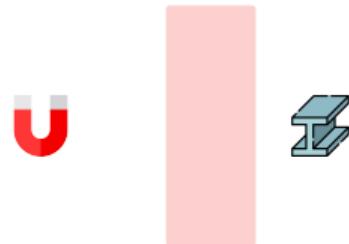
Time step 0



Somewhere **here**
there is a rock

What do we mean with dynamics?

Time step 0



Time step 1

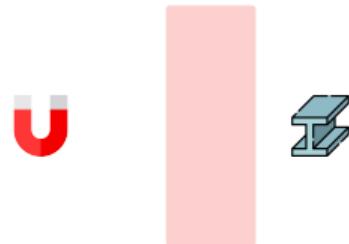


step
physics

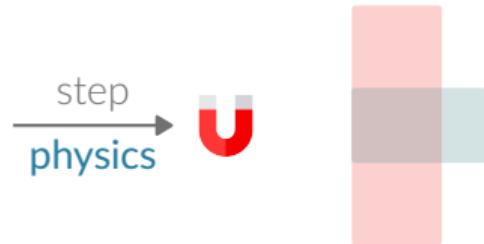
Somewhere **here**
there is a rock

What do we mean with dynamics?

Time step 0

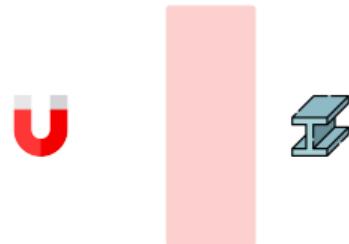


Time step 1



What do we mean with dynamics?

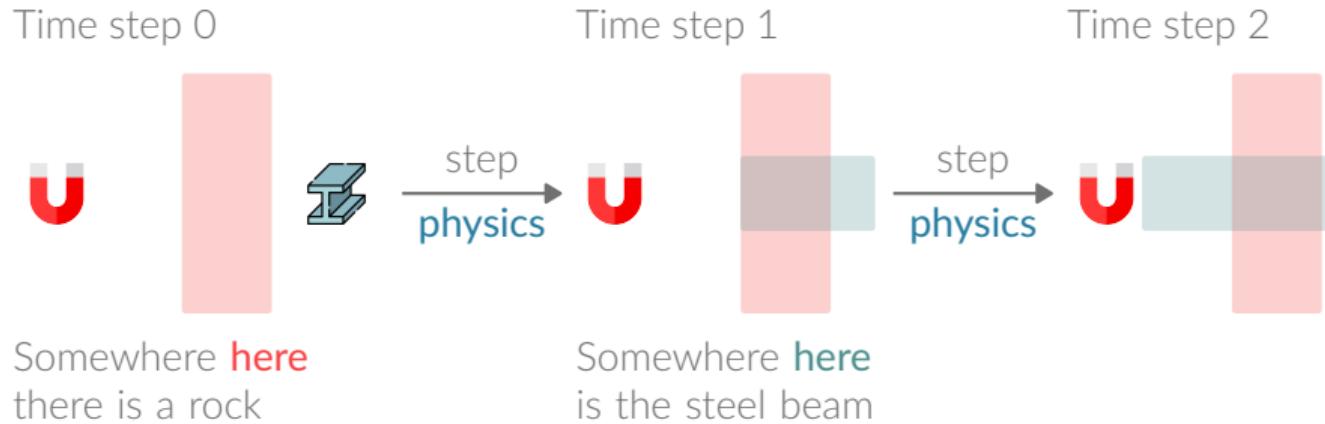
Time step 0



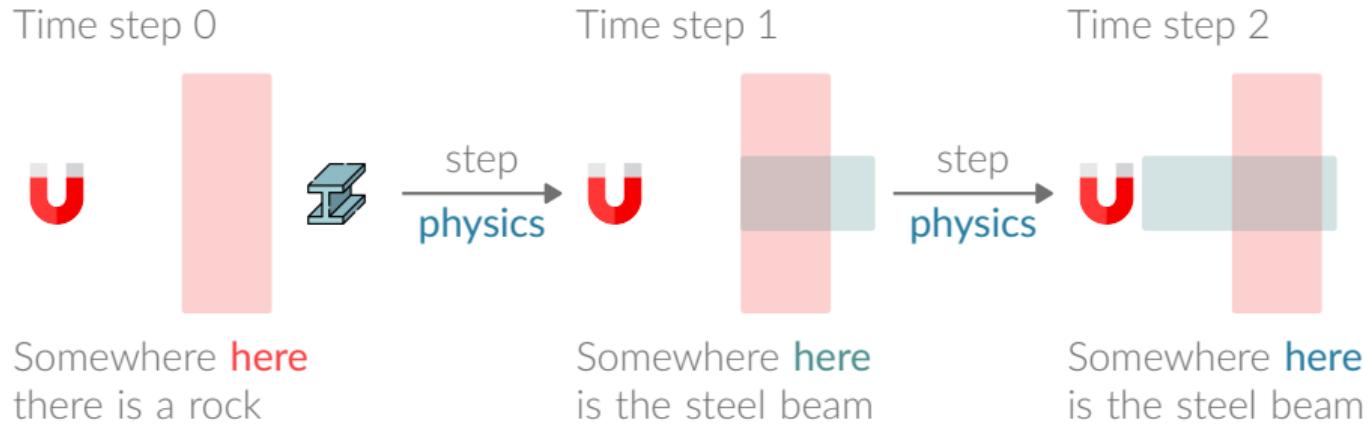
Time step 1

Maybe hit a rock

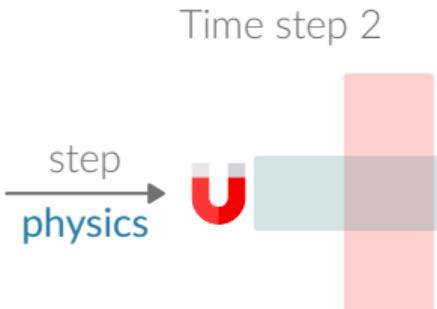
What do we mean with dynamics?



What do we mean with dynamics?

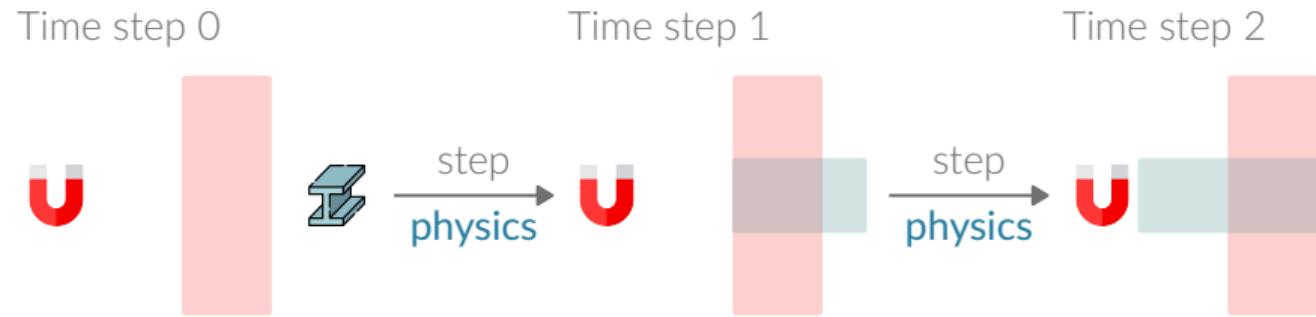


What do we mean with dynamics?

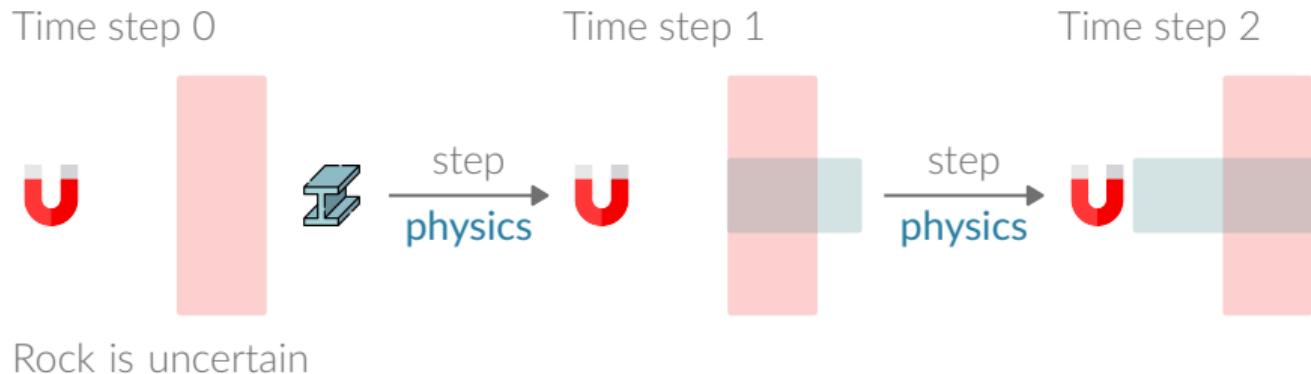


Why? Make predictions of the future such as **when** cables will break

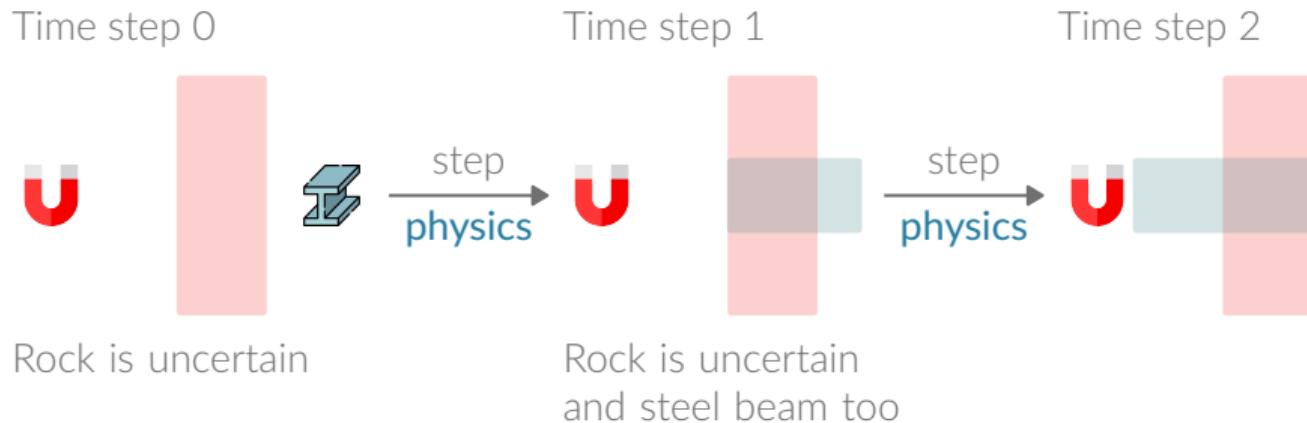
Why are dynamics challenging?



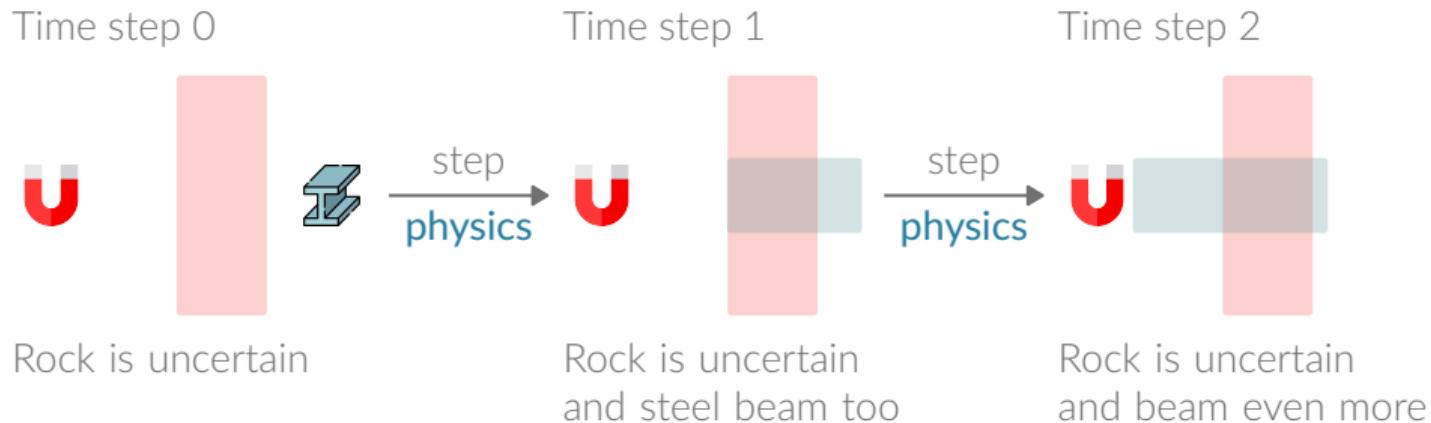
Why are dynamics challenging?



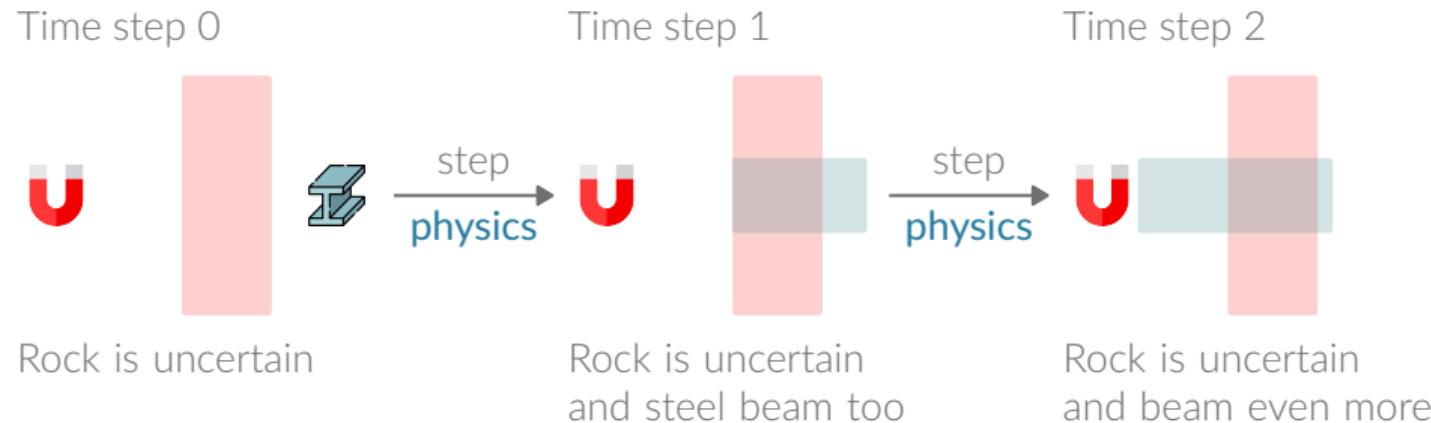
Why are dynamics challenging?



Why are dynamics challenging?



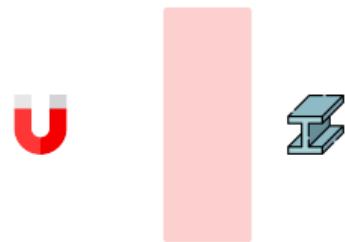
Why are dynamics challenging? Scalability again!



Problem More uncertainty means more options
so number of possibilities explodes again

Looking at limited options scales again

Time step 0



Looking at limited options scales again

Time step 0

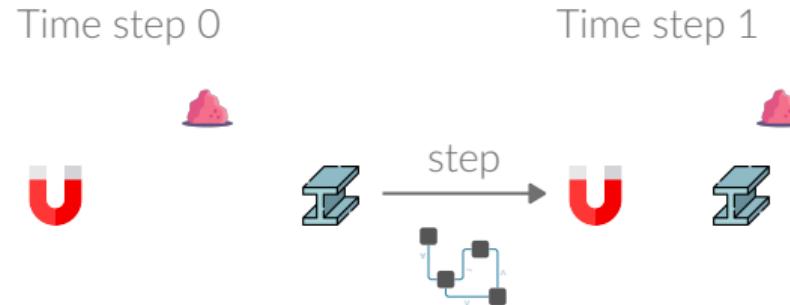


Looking at limited options scales again
with more thinking

Time step 0

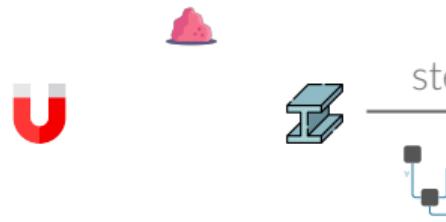


Looking at limited options scales again
with more thinking



Looking at limited options scales again
with more thinking

Time step 0



Time step 1



Looking at limited options scales again
with more thinking



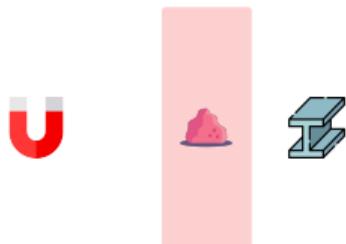
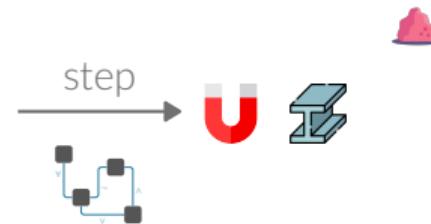
Looking at limited options scales again
with more thinking

Time step 0



Time step 1

Time step 2



Looking at limited options scales again
with more thinking

Time step 0

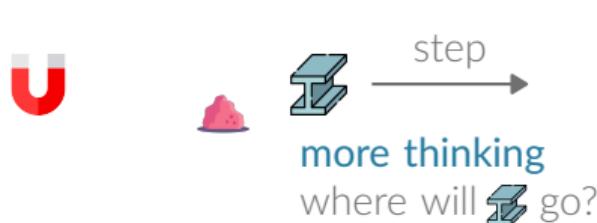


Time step 1

Time step 2

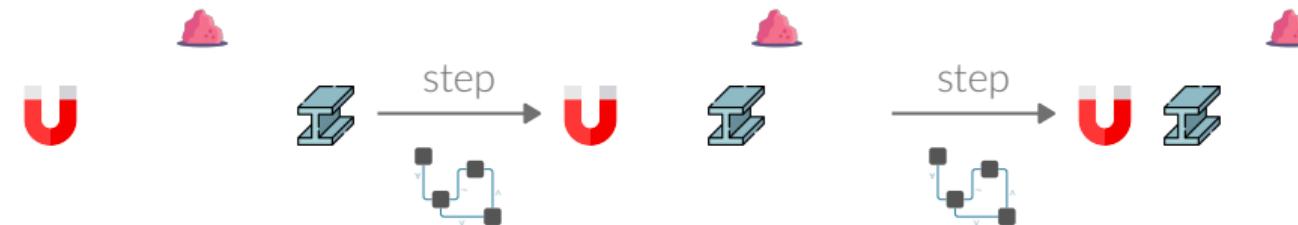
Looking at limited options scales again
with more thinking

Time step 0

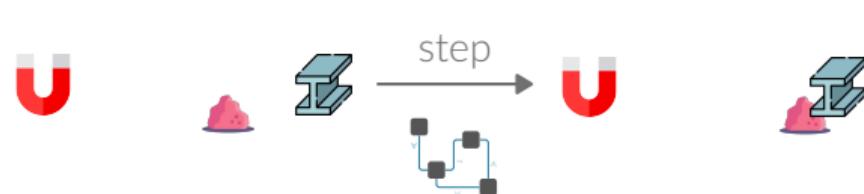


Looking at limited options scales again
with more thinking

Time step 0



Time step 2

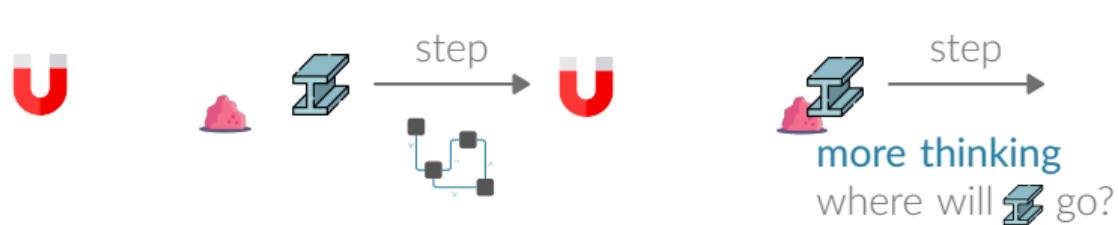


Looking at limited options scales again
with more thinking

Time step 0



Time step 2



Looking at limited options scales again
with more thinking

Time step 0

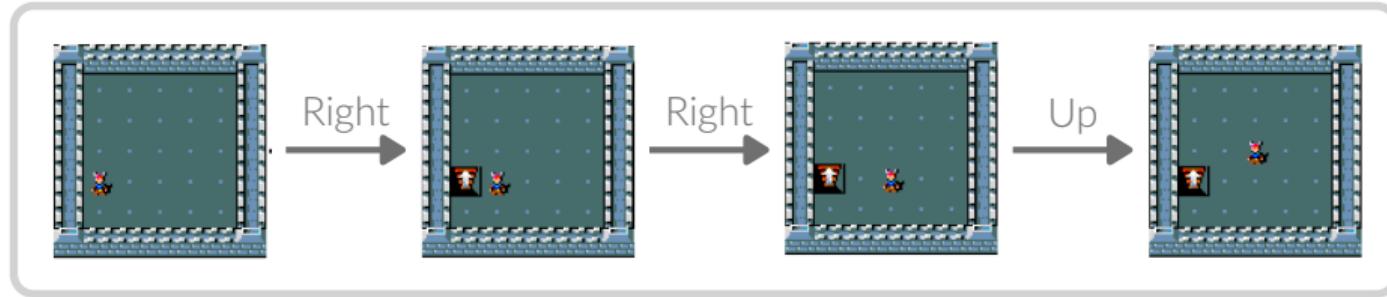


Time step 1

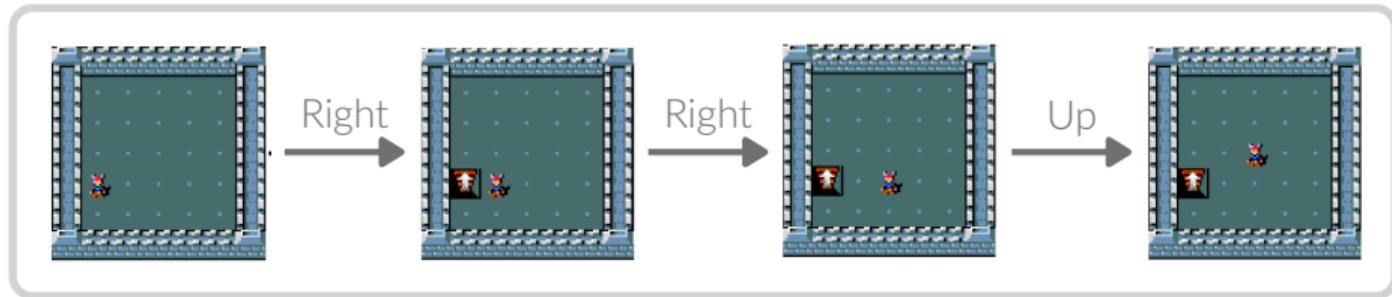
Time step 2



Generative data

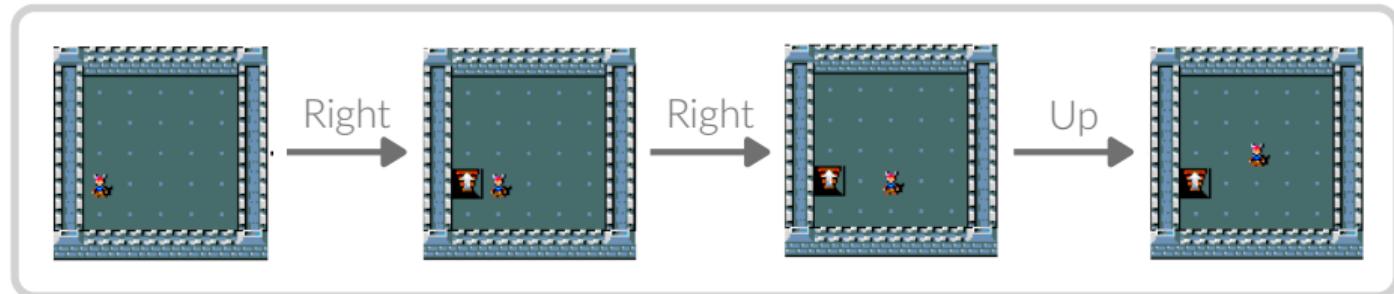


Generative data

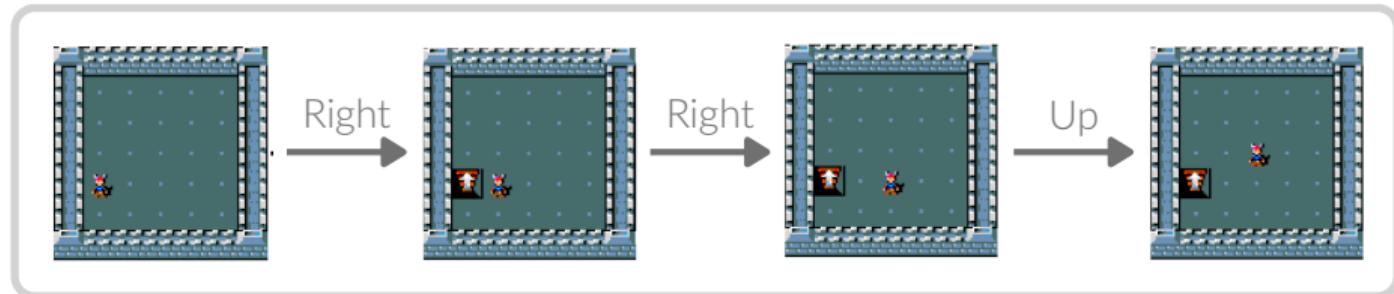


Model

Generative data

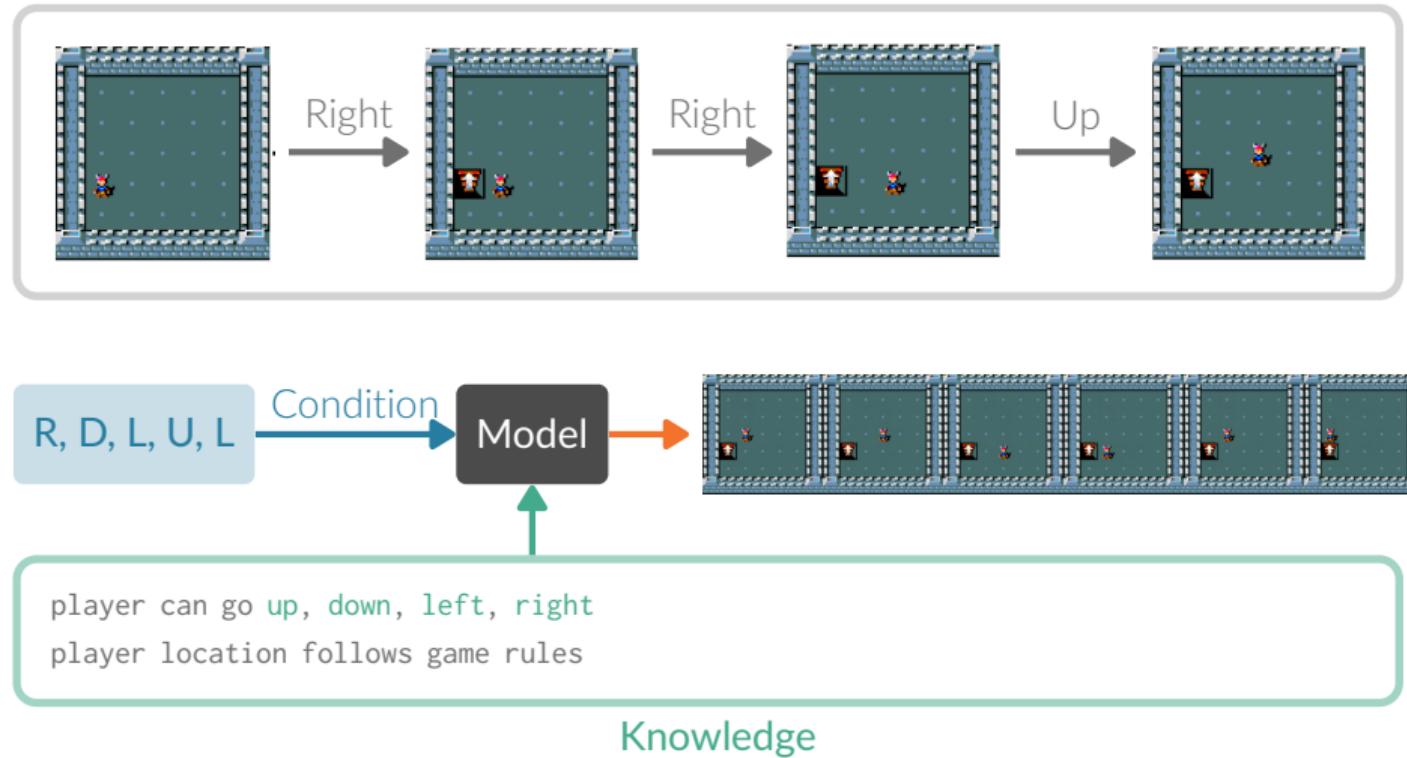


Generative data

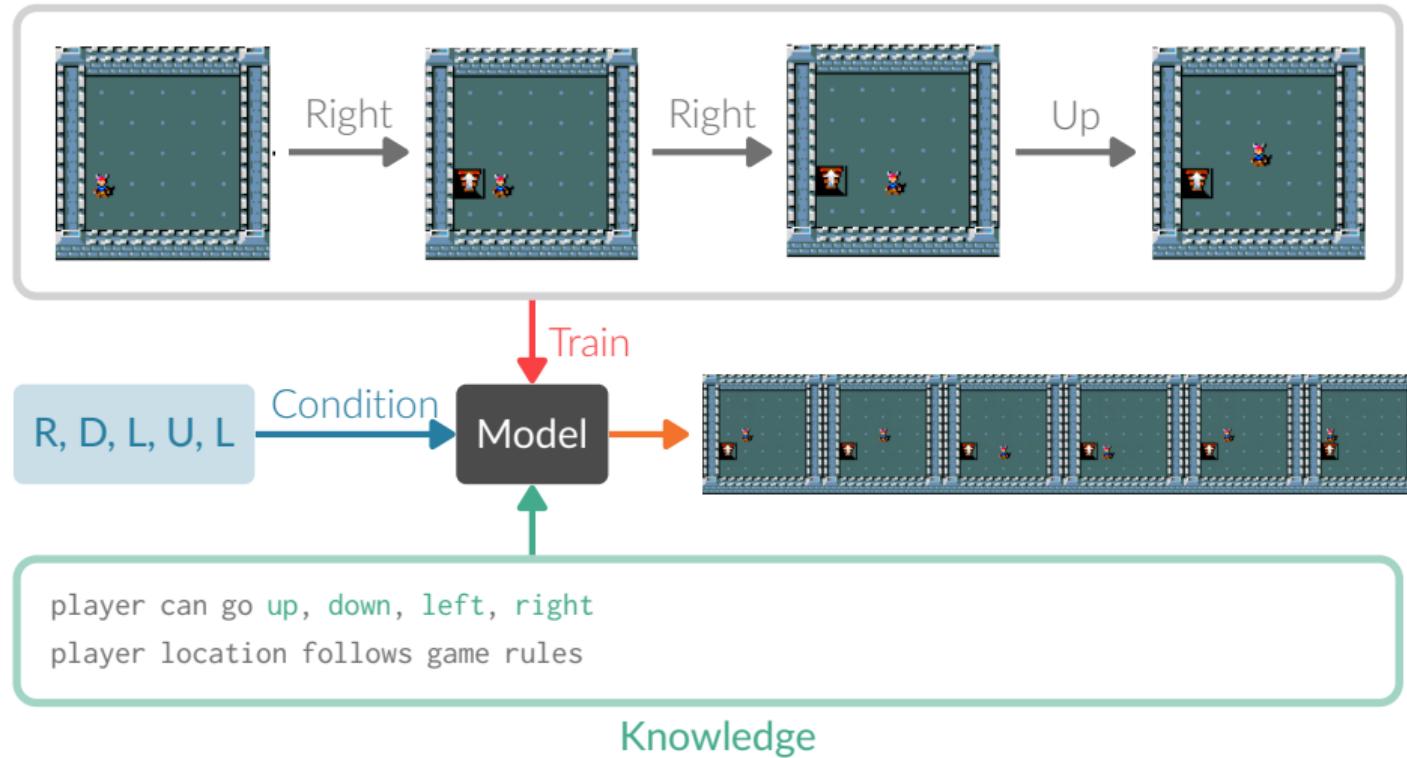


Knowledge

Generative data



Generative data



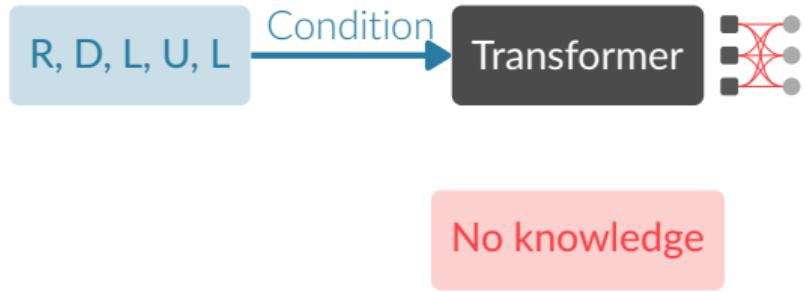
Transformers do not generate logically consistent images



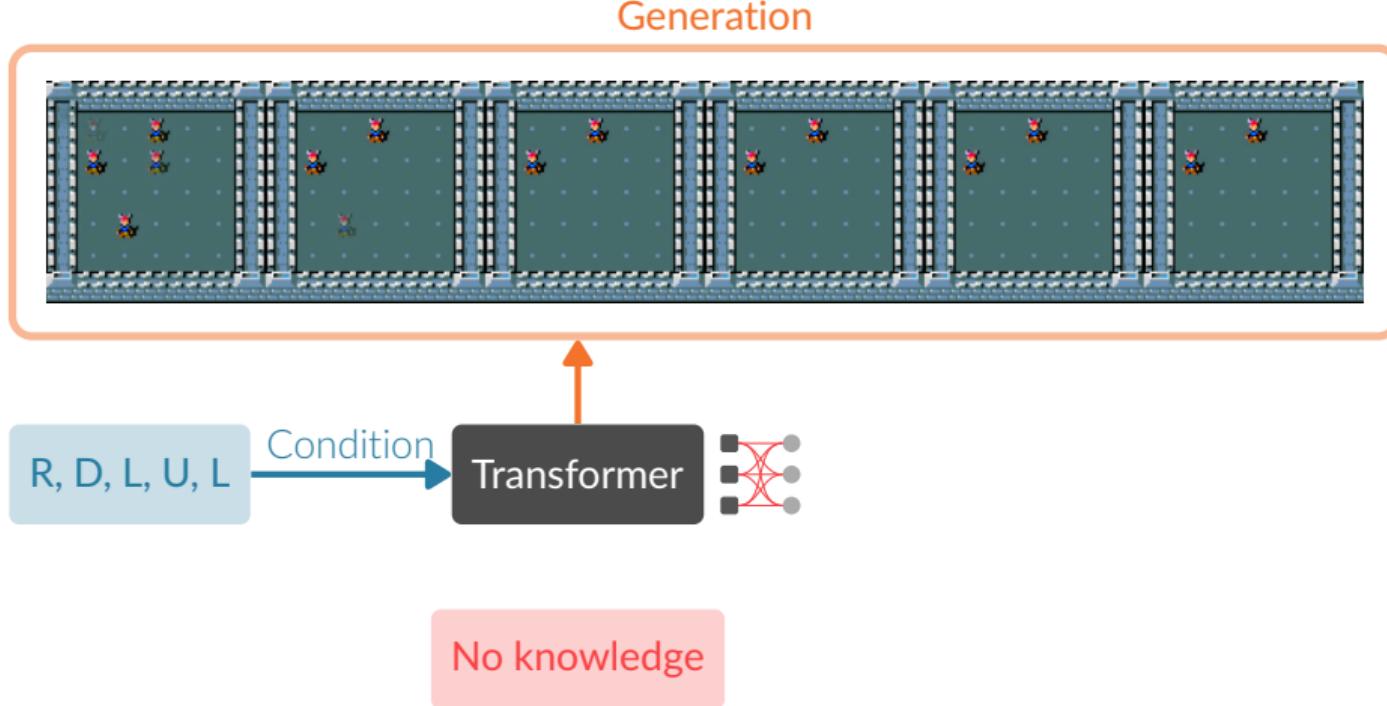
Transformers do not generate logically consistent images



Transformers do not generate logically consistent images



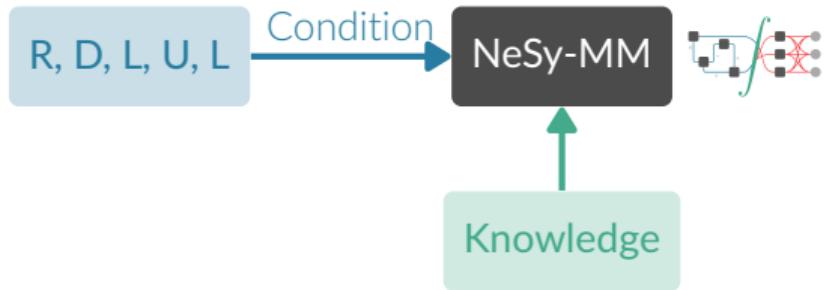
Transformers do not generate logically consistent images



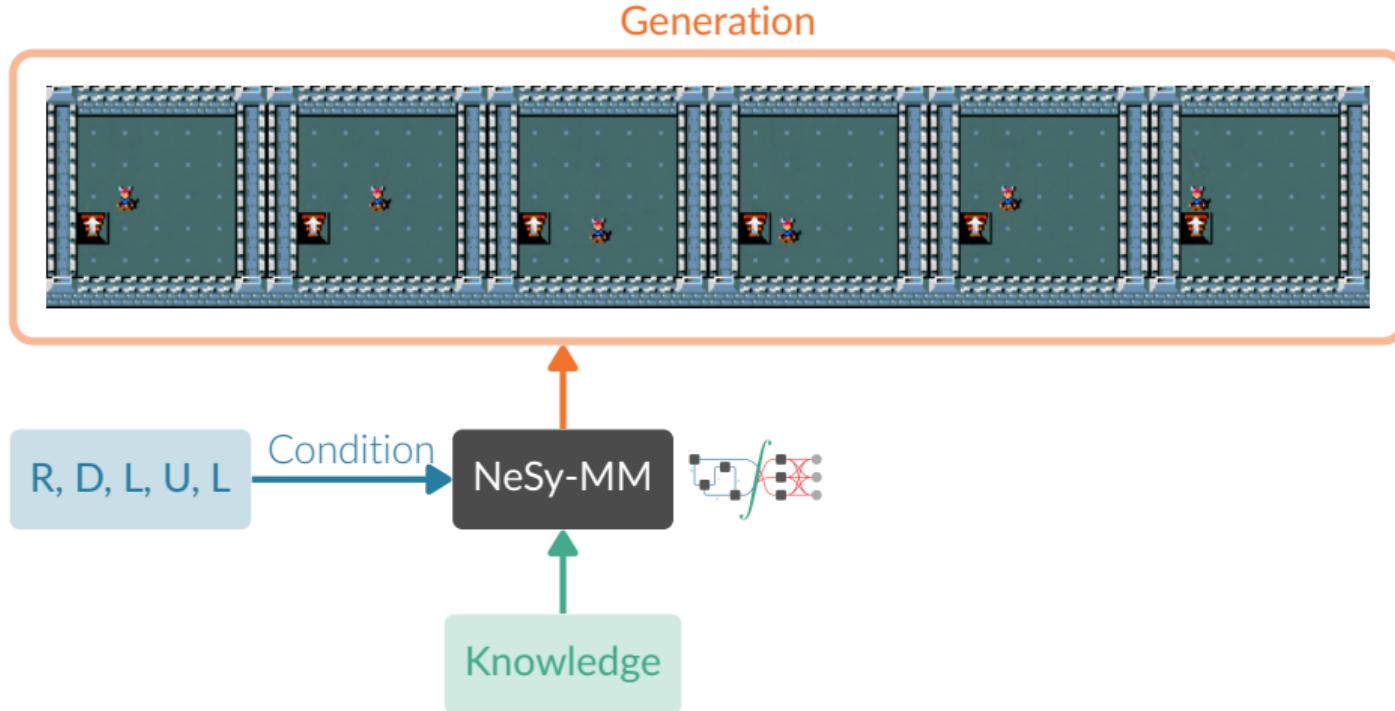
NeSy-MMs do generate logically consistent images



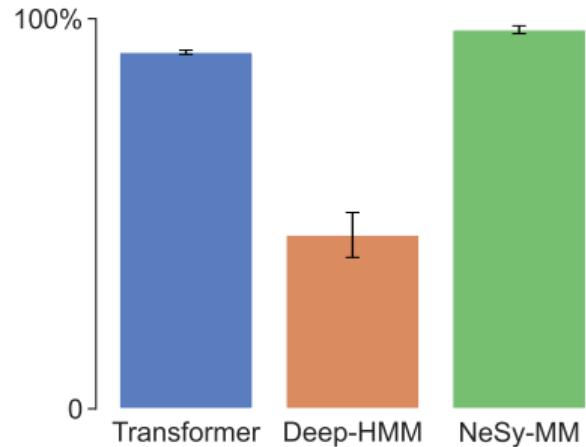
NeSy-MMs do generate logically consistent images



NeSy-MMs do generate logically consistent images

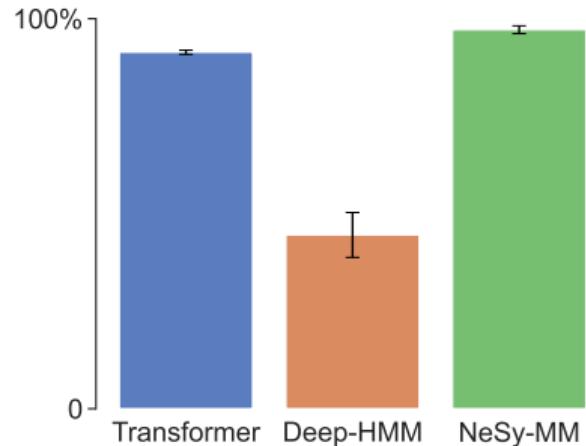


Quantifying logical consistency with reconstruction accuracy

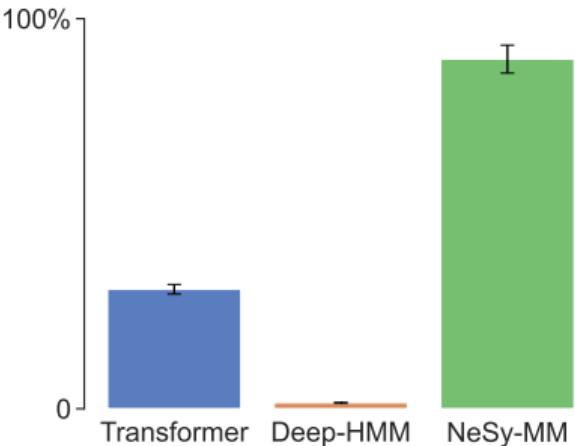


5×5

Quantifying logical consistency with reconstruction accuracy

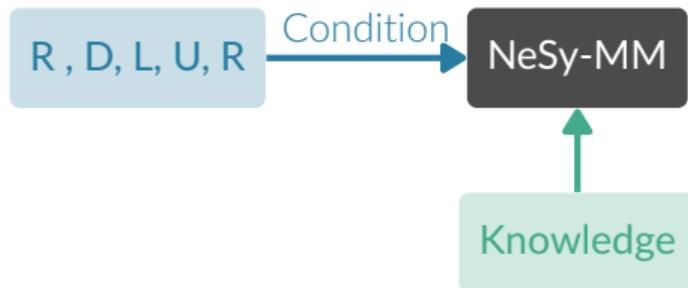


5×5

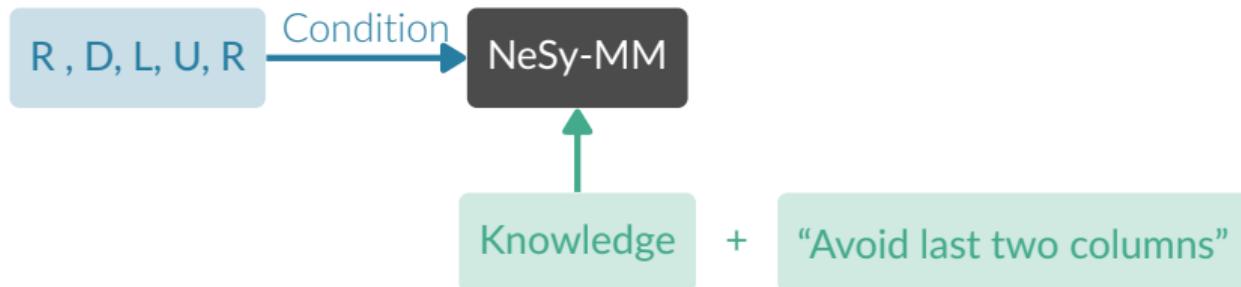


10×10

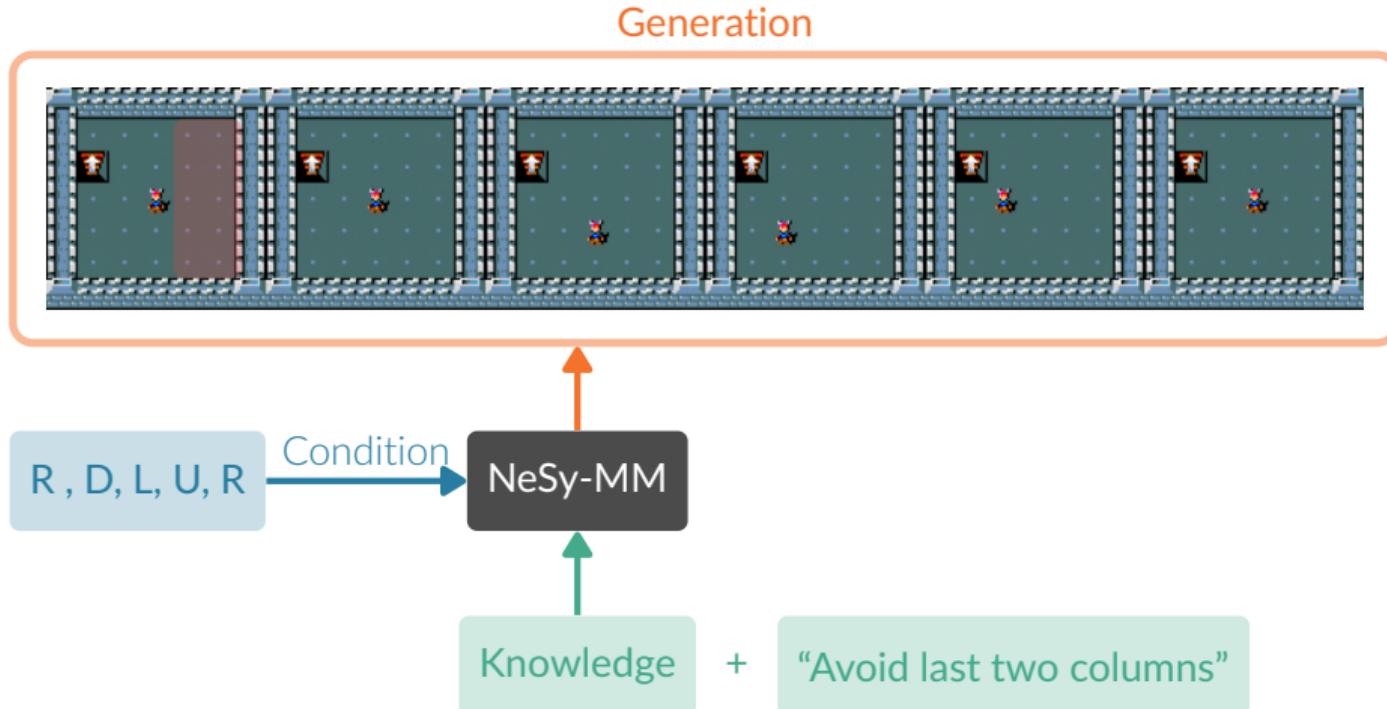
Knowledge can be changed at any time
without having to retrain any models



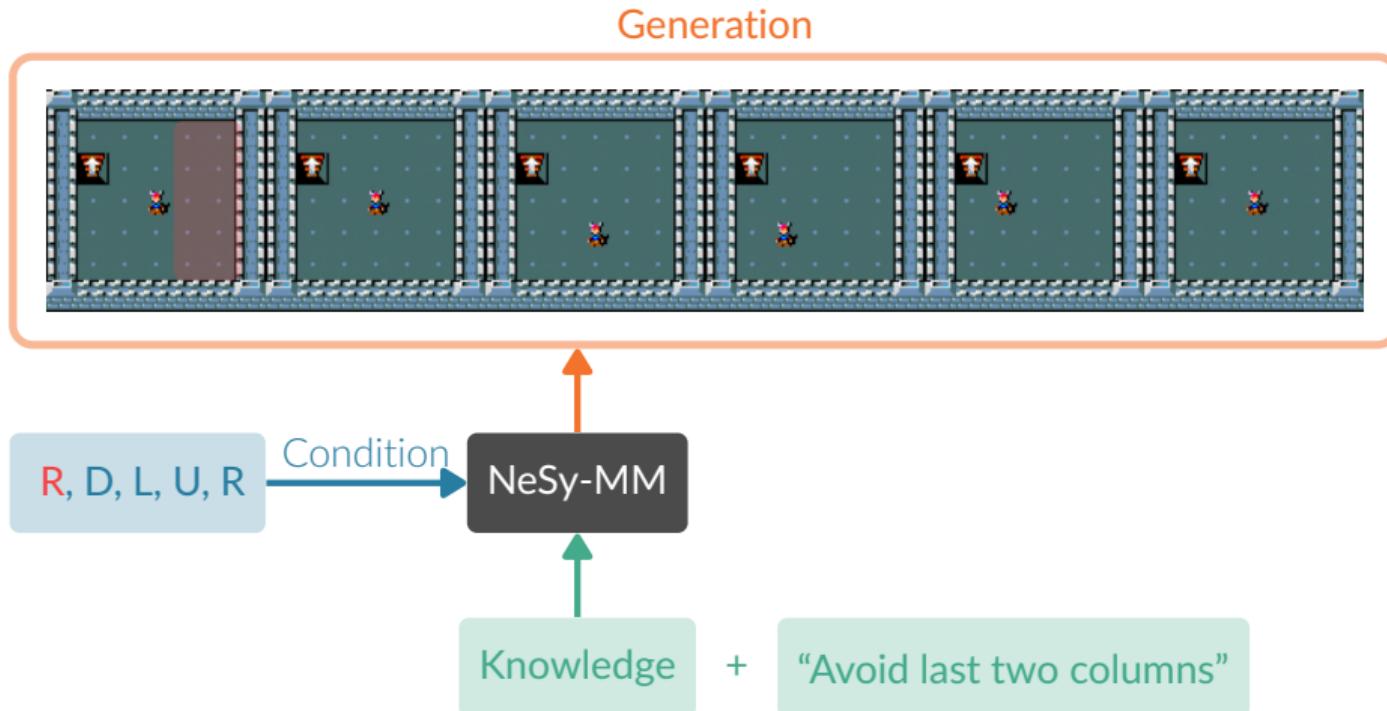
Knowledge can be changed at any time
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Knowledge can be changed at any time
without having to retrain any models



Knowledge can be changed at any time
without having to retrain any models



1 Unifying neurosymbolic AI by abstracting its core concepts

Challenge 1: chaos

2 Scaling neurosymbolic AI to larger problems

Challenge 3: scalability

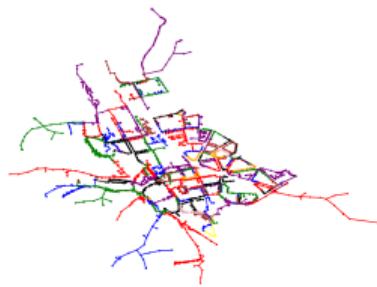
3 Scaling neurosymbolic AI to dynamic problems

Challenge 3: scalability (& Challenge 2: continuous)

But can we now get correct maps of our energy grid?

Almost!

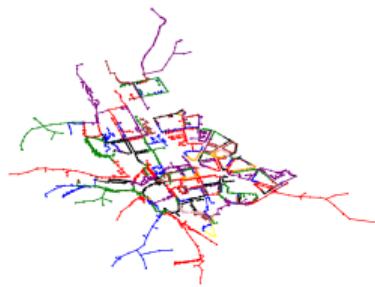
We want to correct thousands
of houses and cables



But can we now get correct maps of our energy grid?

Almost!

We want to correct thousands
of houses and cables



Before we could correct dozens
Now we correct hundreds



Unifying and scaling neurosymbolic AI from abstraction to application

Lennert De Smet

