Preview: Causal Cognitive Architecture 1 (CCA1): Integration of Connectionist Elements into a Navigation-Based Framework

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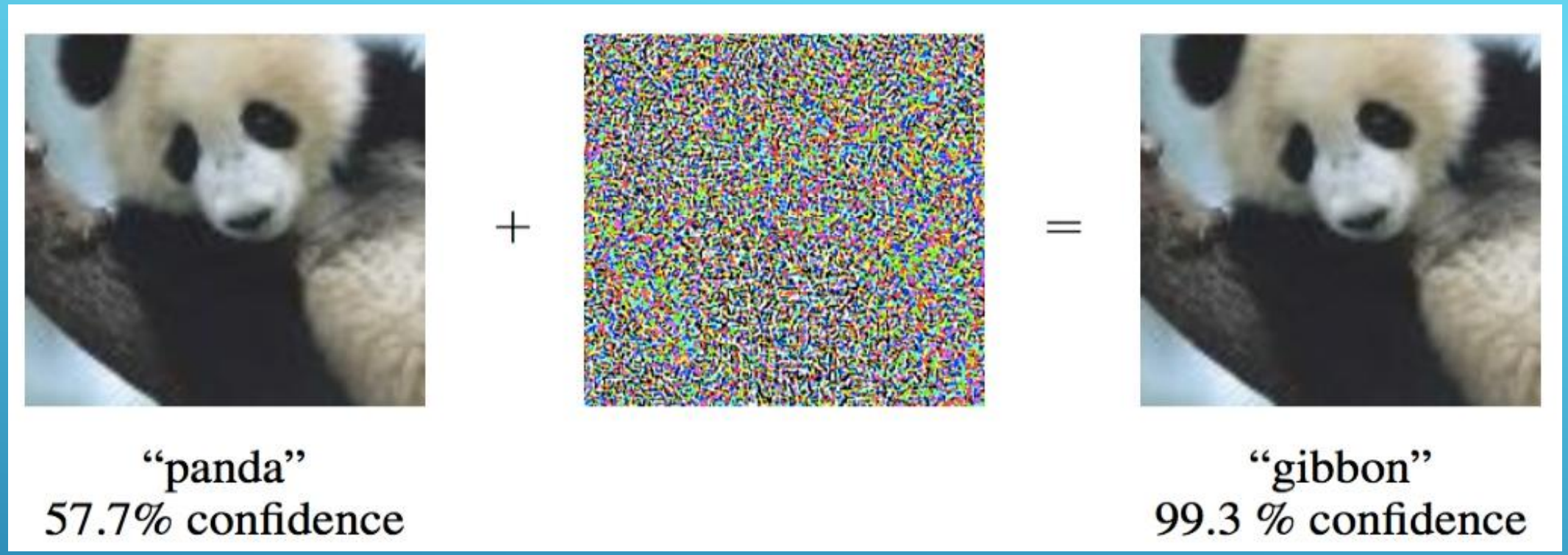
BICA*AI 2020

BICA*AI 2020 Virtual Preconference Session -- Plenary Talk
Sunday, August 30, 2:30pm UTC
2020 Annual International Conference on Brain-Inspired Cognitive Architectures for Artificial Intelligence
Joint VR Track October 10-11, 2020

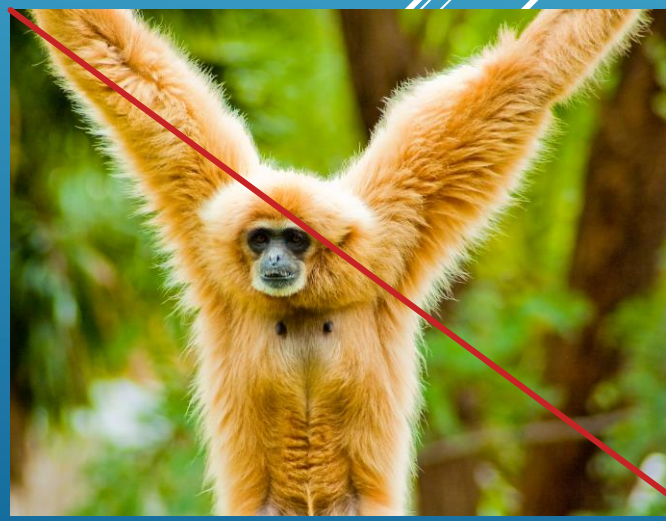
The problem: The *Neural Symbolic Gap*

- **Neural Network** – phenomenal image processing and reinforcement learning
- **Child** – phenomenal causal learning with few examples (eg, Gopnik)



Goodfellow,I.J., Shlens,J. and Szegedy,C. (Google Mountainview), Explaining and Harnessing Adversial Examples, ICLR 2015.

It’s still a Panda – and the 3 year old boy would know this!!
(and….. 3 year old only needs 1 or 2 photos for training, not 1000s)



Deep Learning Neural Network	3 Year Old Human Child
Pattern Recognition →Recognize the World	Model Building +also Pattern Recognition →Explain the World
Need 1000's examples for learning	A few examples enough

The solution: *Ability to Generate Causal Behavior*

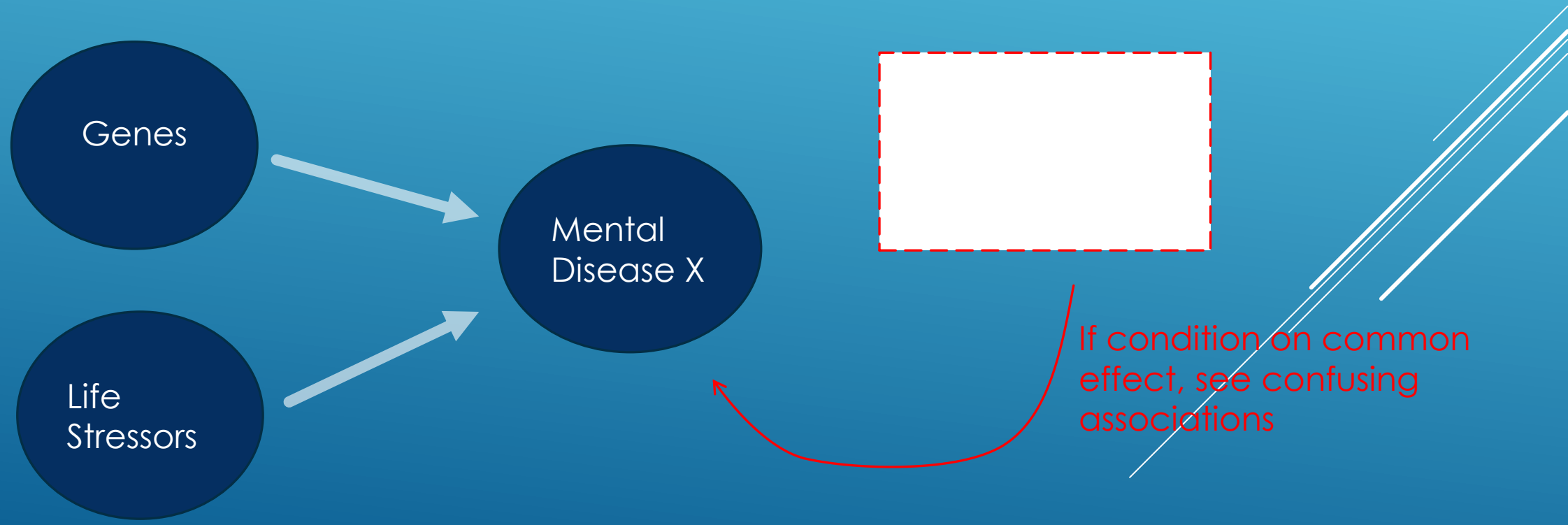
‘Reptilian’ and ‘Mammalian’ Brain – Associative Functioning

‘Human’ Brain, AGI – Causal Functioning

Directed Acyclic Graphs ('Causal Graphs') Counterfactual Theory

-Useful for ***Analyzing*** Causality, eg, epidemiology, genomics

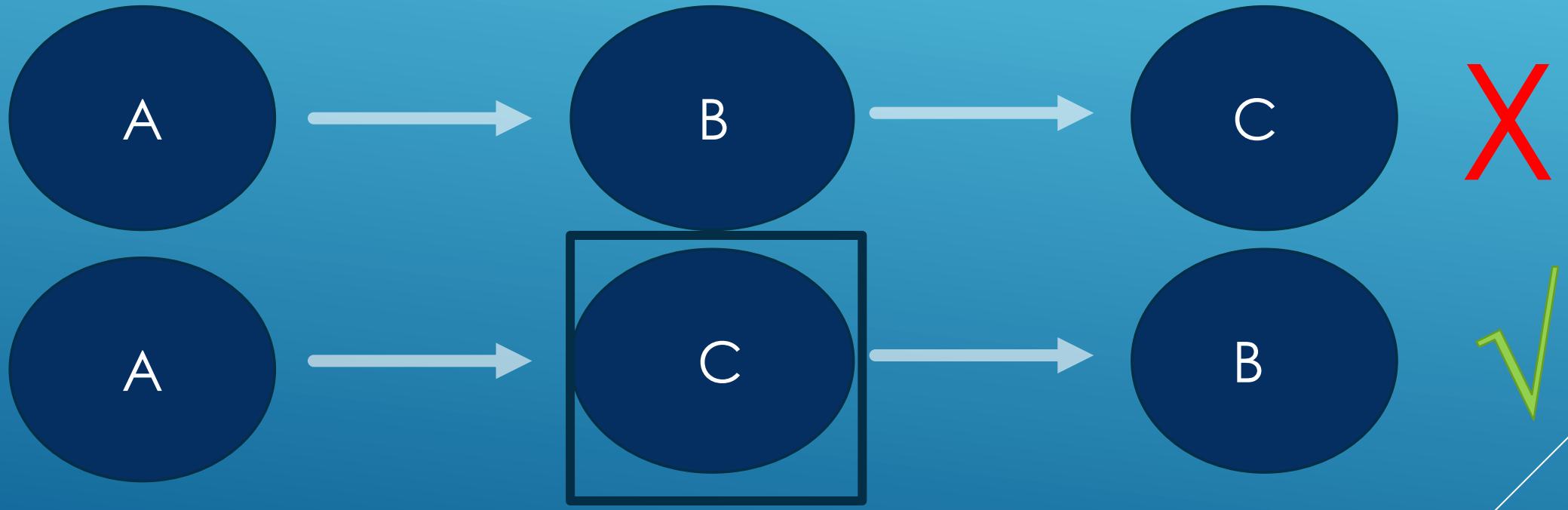
-Less Useful for ***Generating*** Causality, eg, AGI



Causal Discovery

Try to learn causal relationships from the data

eg, Data shows A & B are independent if we condition on C, but dependent if we don't



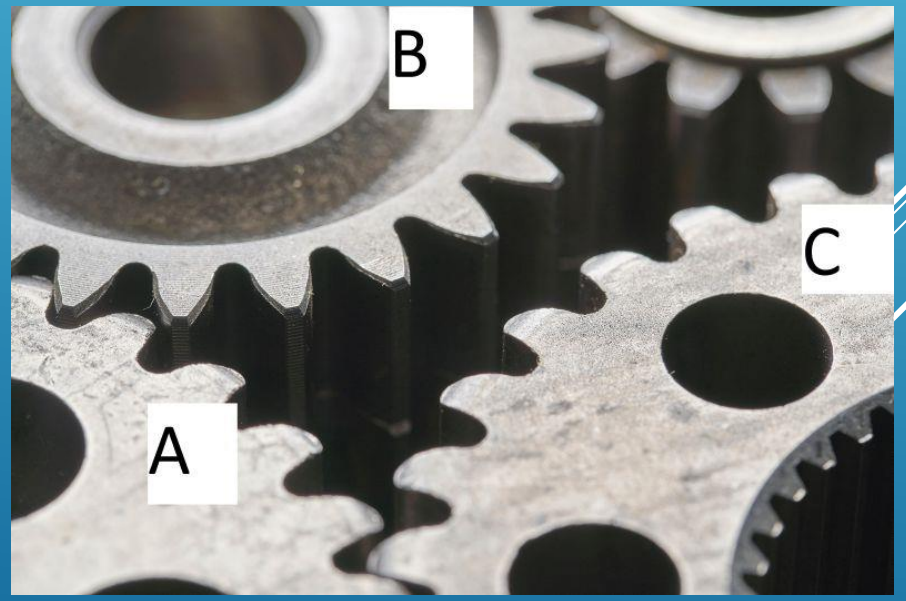
other causal models will also exist given this data....

Directed Acyclic Graphs ('Causal Graphs')
Counterfactual Theory
Causal Discovery

-Useful for ***Analyzing*** Causality
eg, epidemiology, genomics

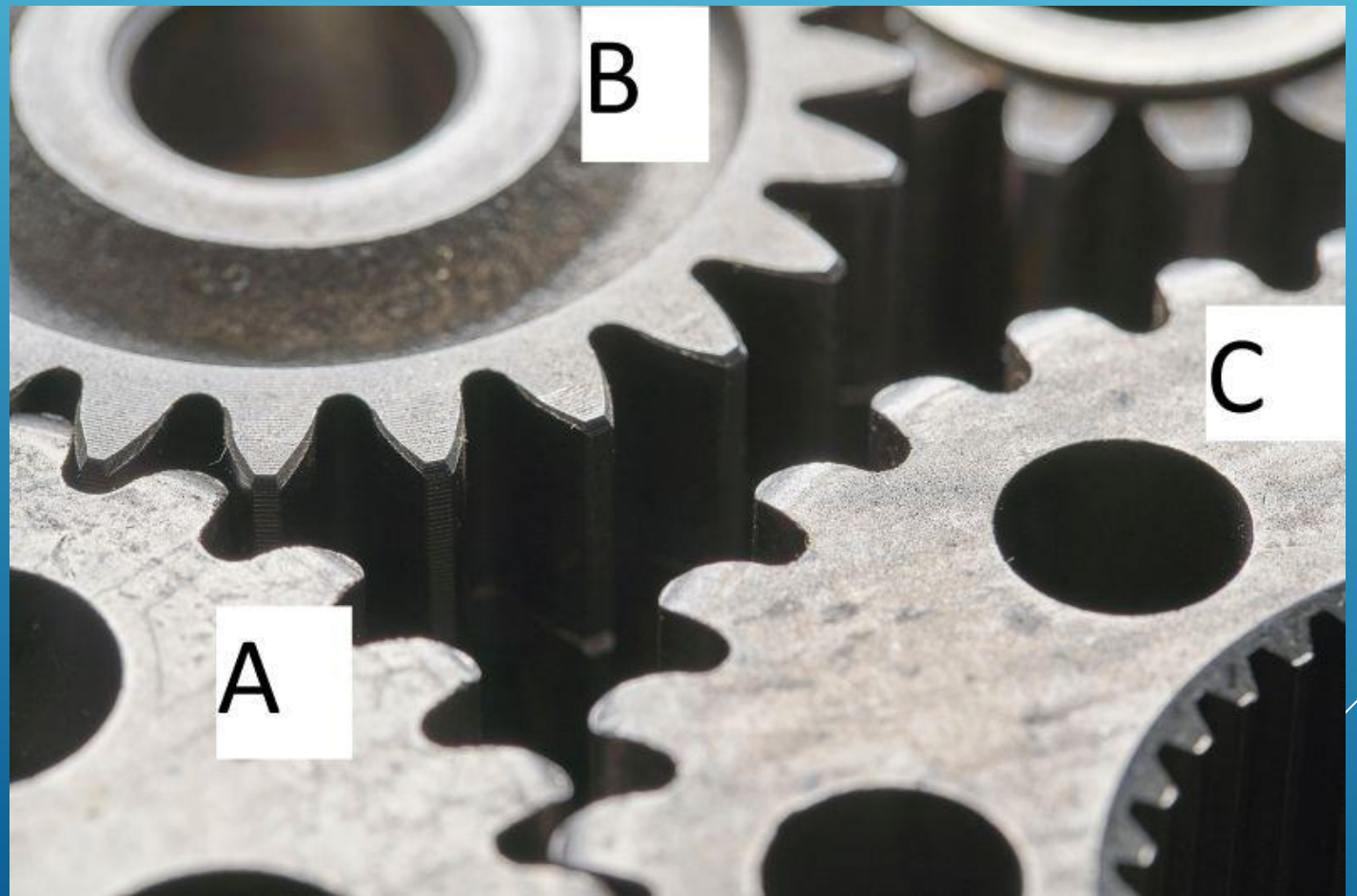
-Less Useful for ***Generating*** Causal Behavior
eg, AGI

We want a mechanism for generating causal behavior in the real world



-Agent (AGI, cognitive architecture, etc) *has never seen the machine below* (or even a similar machine).

-If Gear C is turned, what happens to Gear B?



-Child has never put green and pink block together before, and he has never put them at an angle.

-With no previous examples can he do this now?

-Rescue robot goes out into rain forest, and wants to cross this river. Noisy and fast flow. Never saw river like this before.
-Should it cross?

No.

Kaieteur Falls, Guyana

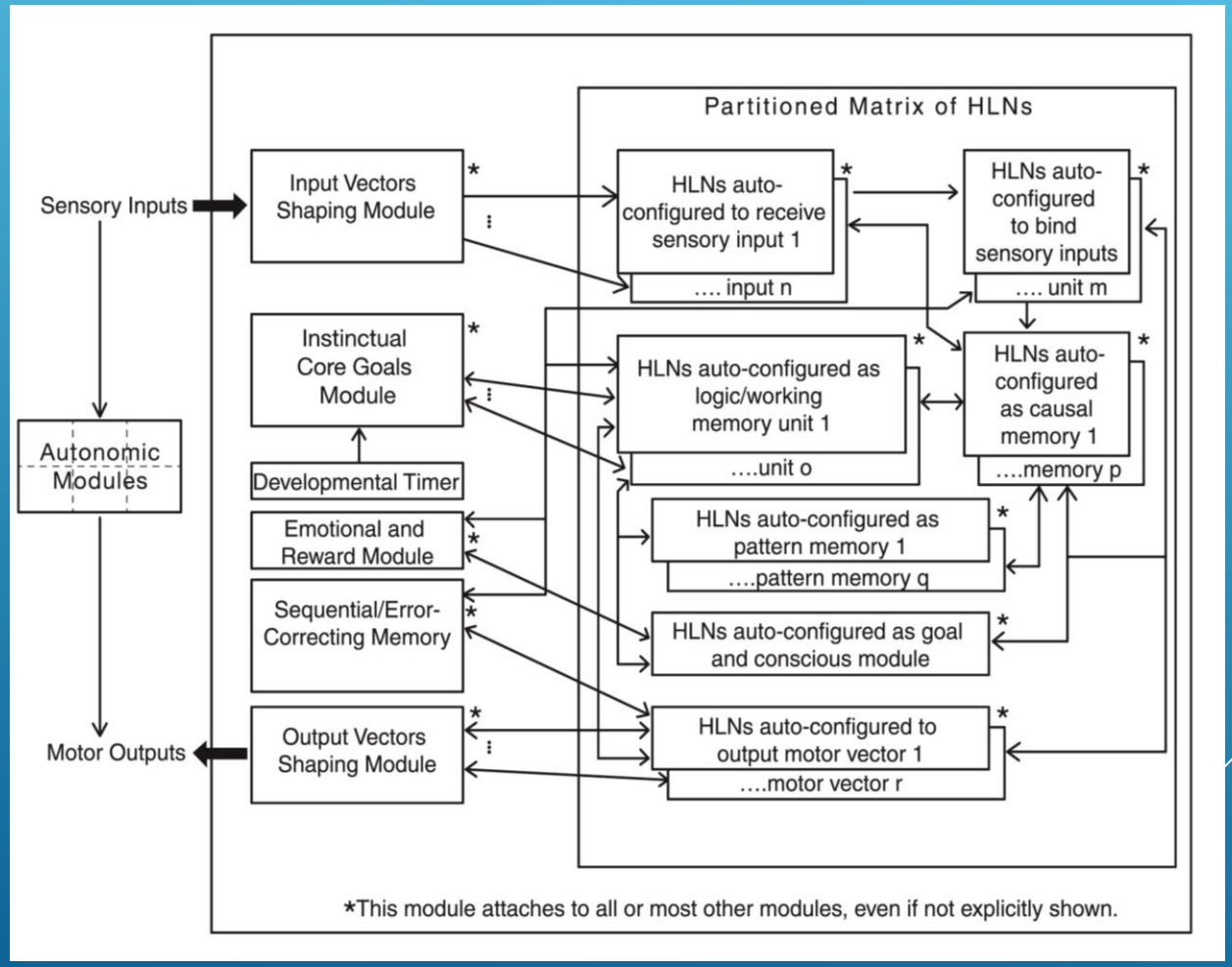
Causal Cognitive Architecture 1 (CCA1)

- ***Generates* Causal Behavior**

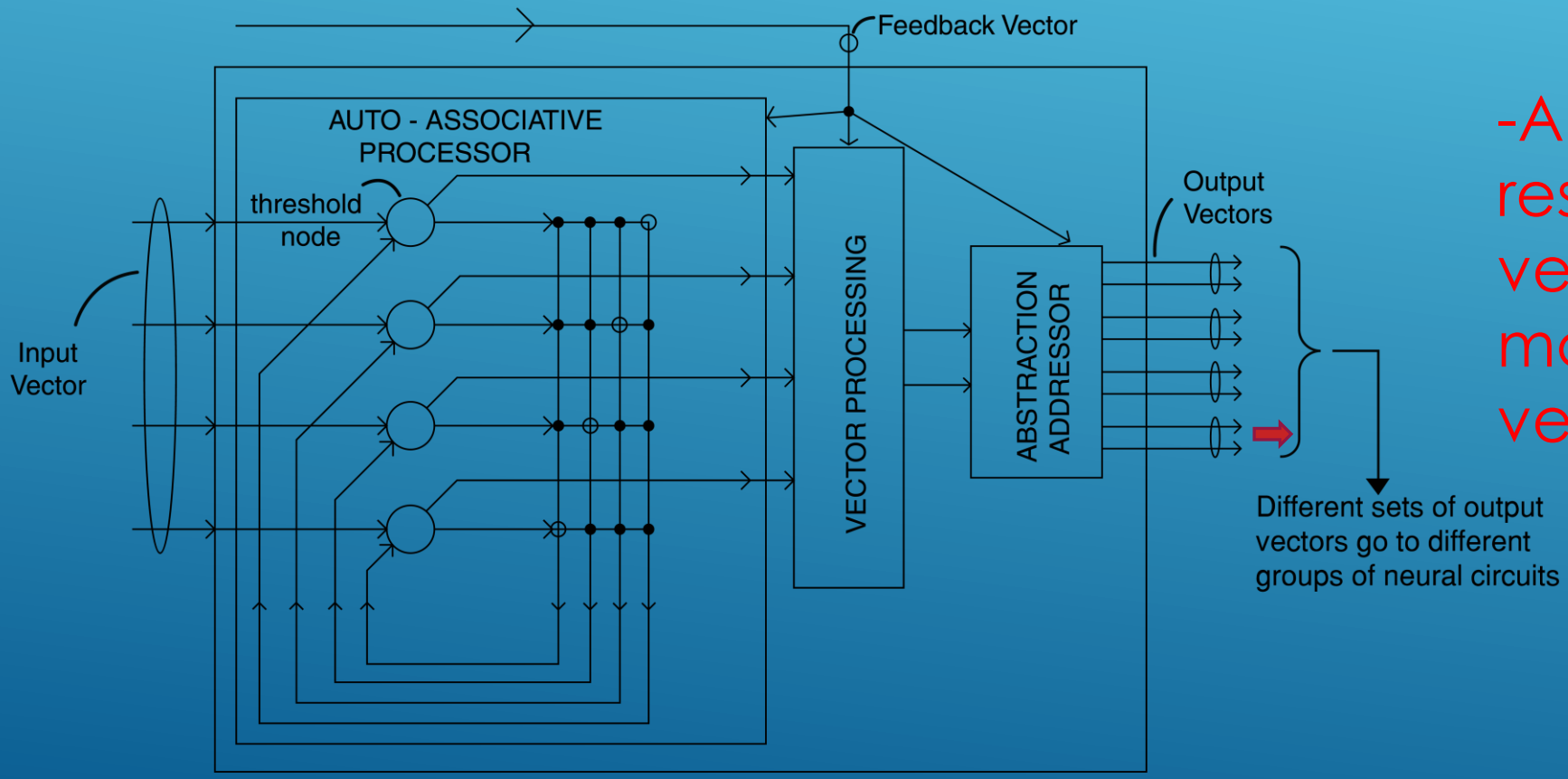
- Mesoscopic brain inspired cognitive architecture – good balance of low/mid level and high level components and features

- A pragmatic solution to the neural-symbolic problem

Derived from my previous work on the Meaningful-Based Cognitive Architecture (BICA 2018, 2019)



Basic Unit: **Hopfield-*like* Network** (‘**HLN**’)



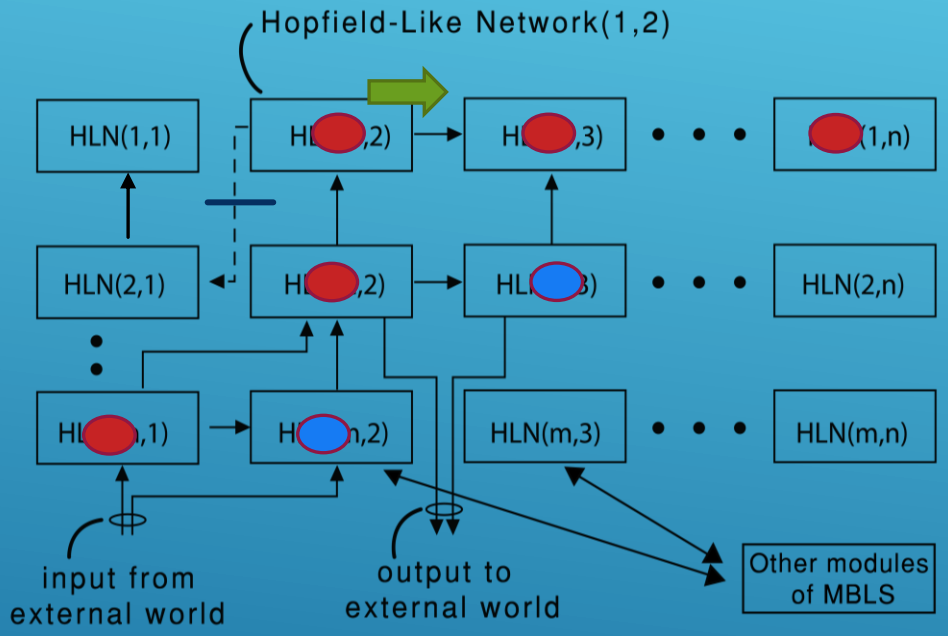
-Auto-Associative Processor is a pattern recognizer

-Abstraction addressor in response to the feedback vector, decides which of many possible output vectors to use

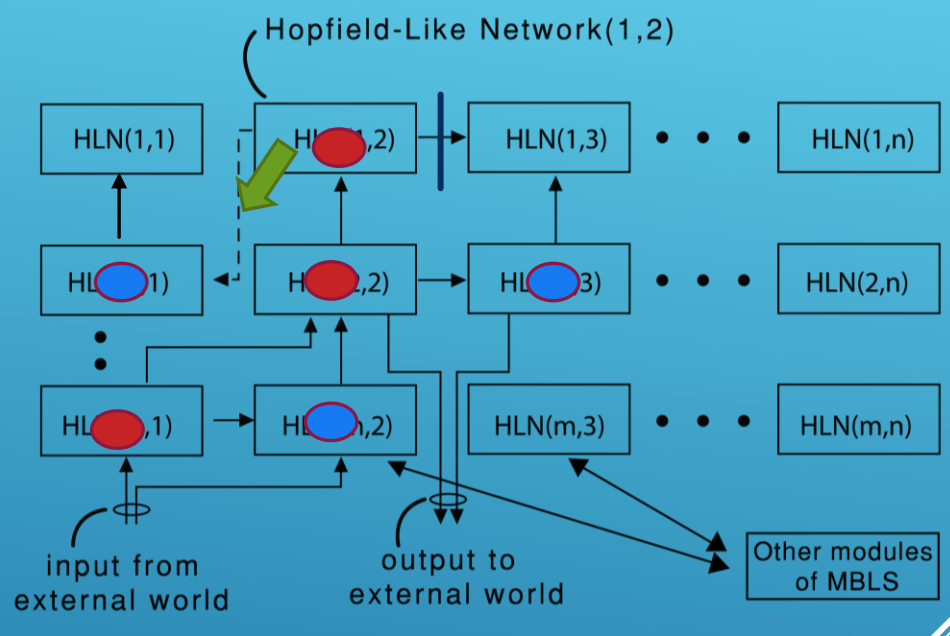
Meaningfulness – via Shannon Entropy

$H = -\sum_i P(x_i) \log_2 P(x_i)$ ←*Shannon entropy*

$M = 1/H$ ←*Meaningfulness*



Reconfiguration A



Reconfiguration B

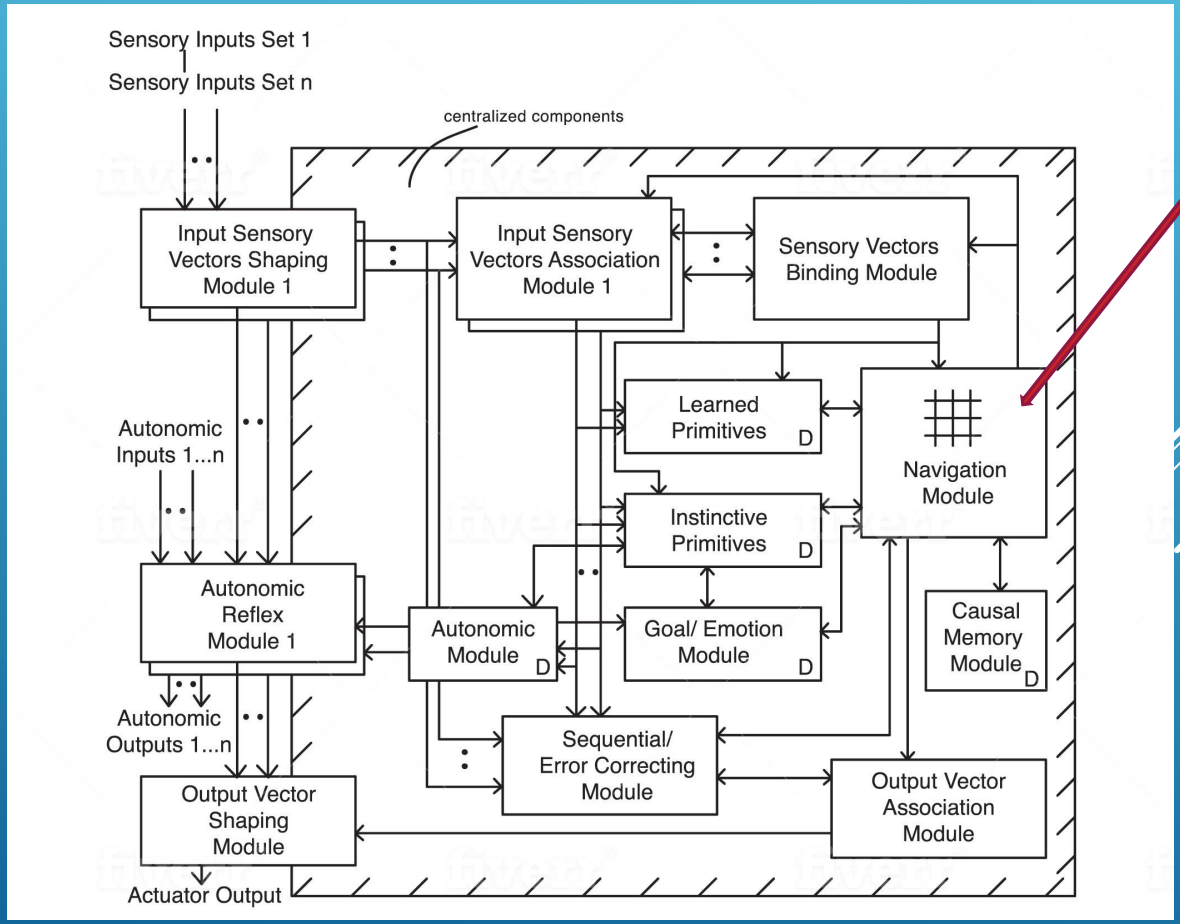
5 HLNs 'On', 2 HLNs 'Off' vs. 3 HLNs 'On', 3 HLNs 'Off'

p(ON)=5/7, p(OFF)=2/7 vs. p(ON)=3/6, p(OFF)=3/6

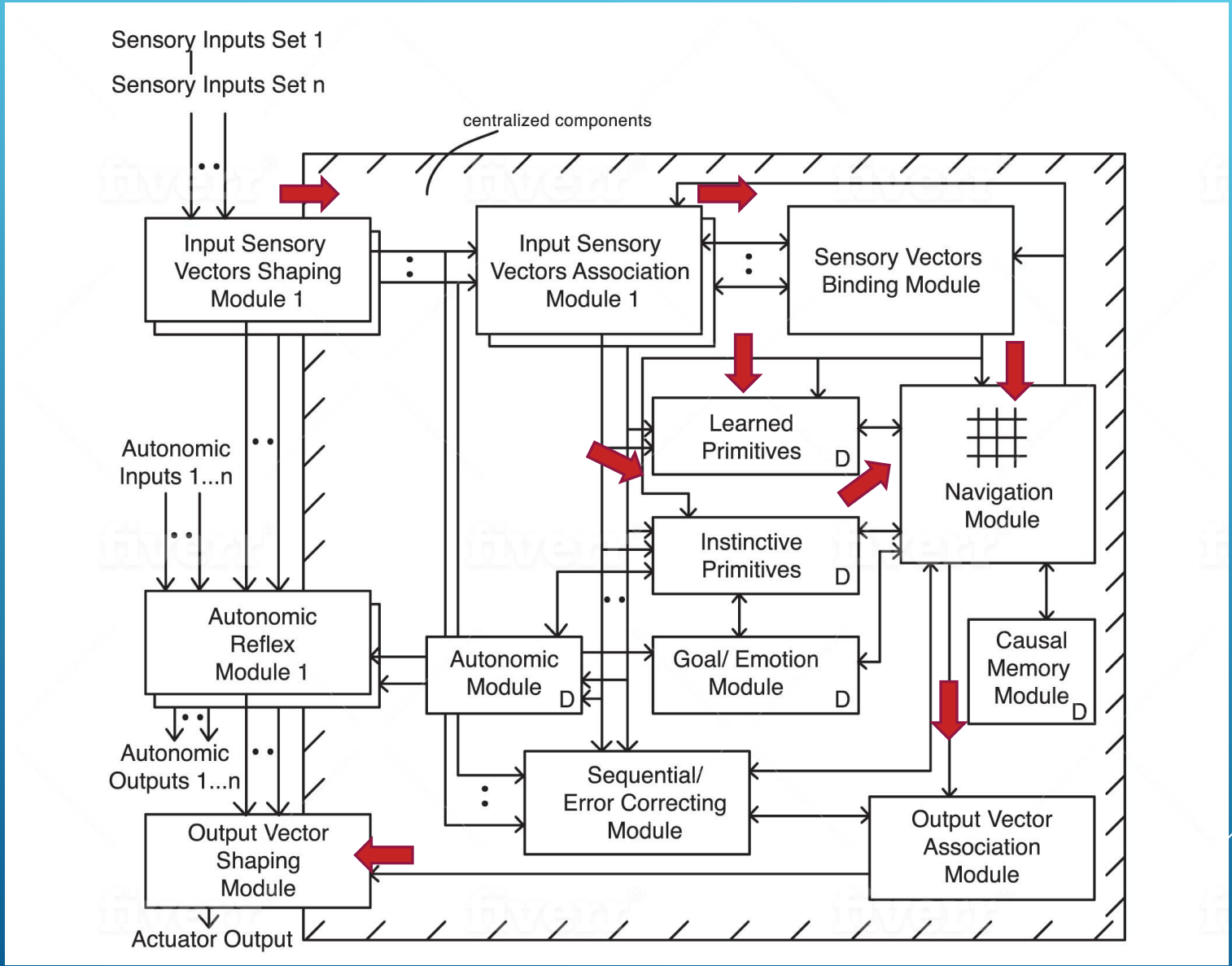
H= 0.86 → **M=1.2** vs. H=1.0 → **M=1.0**

(via Counting: 5 on vs. **via Counting: 3 on)**

CCA1 adds a Navigation Module
Lots and lots of small maps
Simple operations on these maps



Let's see some examples how CCA1 works…..



Hiker lost in the woods…..

Robot goes to the forest to save the hiker….

← Robot

← *Controlled by an CCA1*

As convenience, I will say: ***"CCA1"***

"CCA1" *= Robot + CCA1*

Choose pre-causal functioning of CCA1

Command Prompt - cca1_2020

```
Please choose type of "hippocampus"/"brain" which, of course,
 only loosely approximates the biological equivalent:
1. Lamprey hippocampal/brain analogue
2. Fish hippocampal/telencephalon analogue
3. Reptile hippocampal/pallium analogue
4. Mammalian hippocampus - note: meaningfulness, precausal
5. Human hippocampus - note: meaningfulness plus full causal features
6. Augmented Human level 1 - simultaneous multiple navigational threads
7. Augmented Human level 2 - algorithm center in each navigational module
Please make a selection:
```

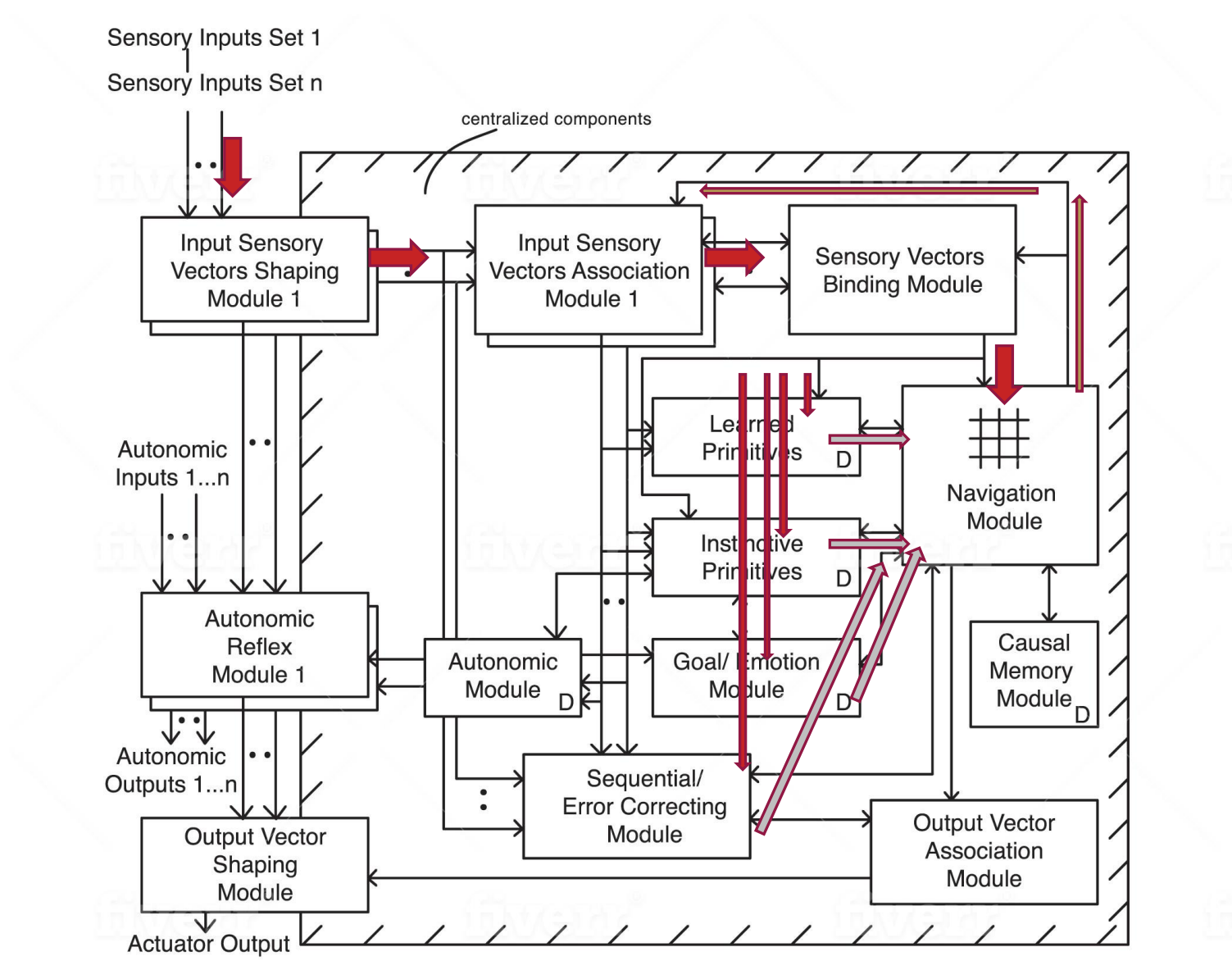
CCA1 must navigate to the lost hiker's square

Command Prompt - cca1_2020

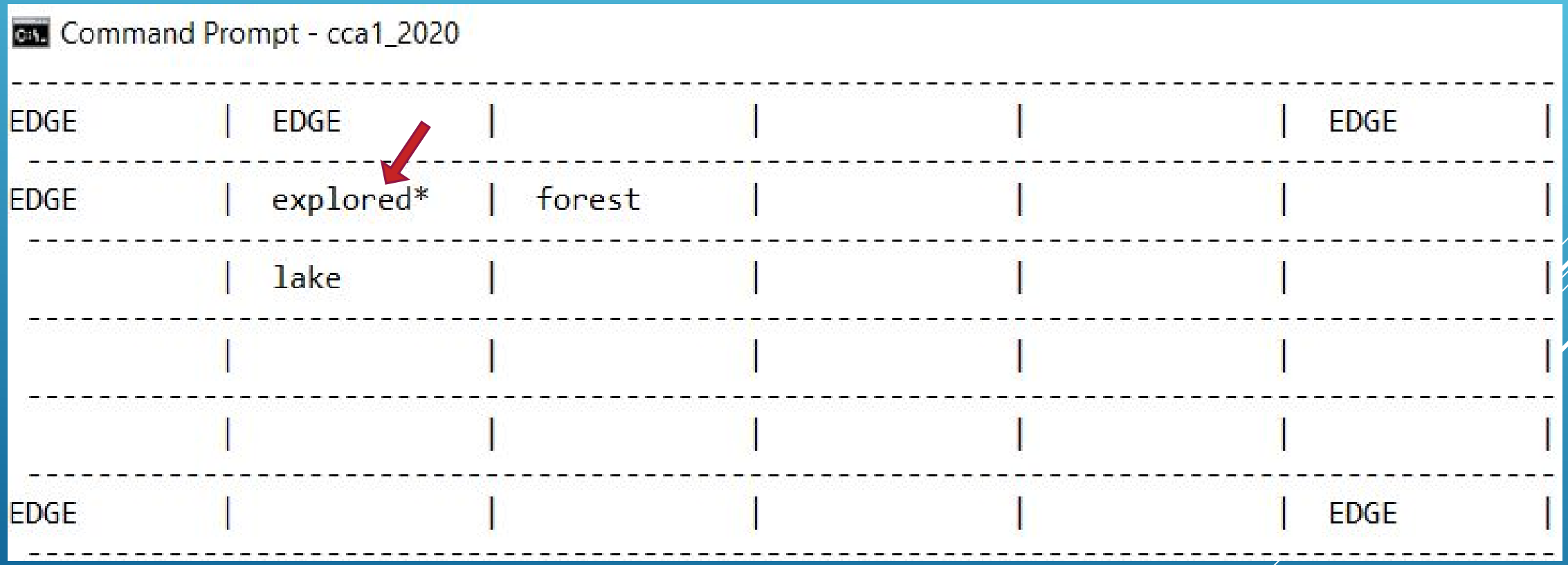
```
hiker position set to:  4 2

Bird's-Eye View of Forest (CCA1 does not have this view)
```

EDGE	EDGE	EDGE	EDGE	EDGE	EDGE
EDGE	CCA1 *	forest	sh_rvr	forest	EDGE
EDGE	lake	forest	forest	forest	EDGE
EDGE	forest	wtrfall	forest	forest	EDGE
EDGE	forest	hiker	forest	forest	EDGE
EDGE	EDGE	EDGE	EDGE	EDGE	EDGE

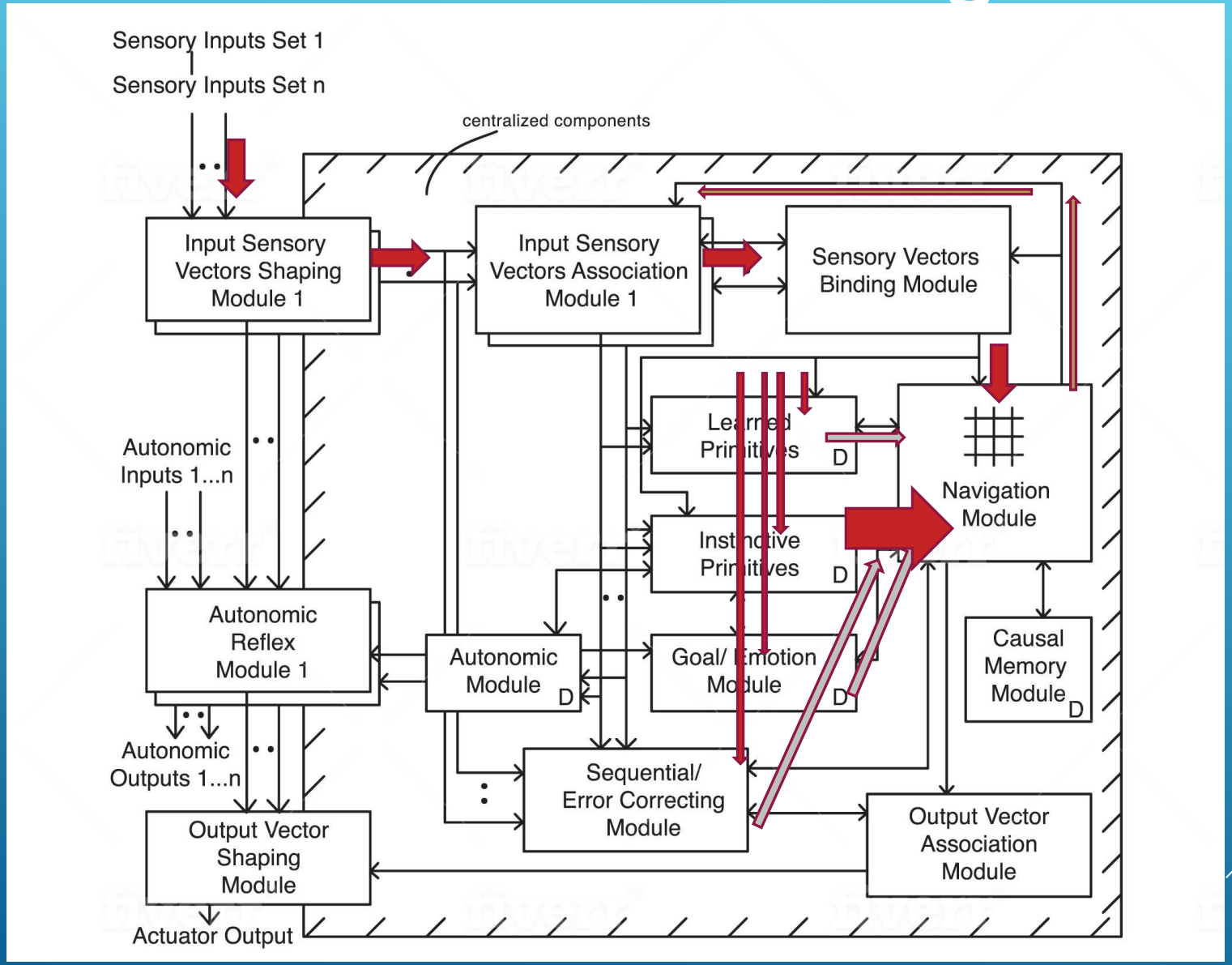
CCA1 – perception….



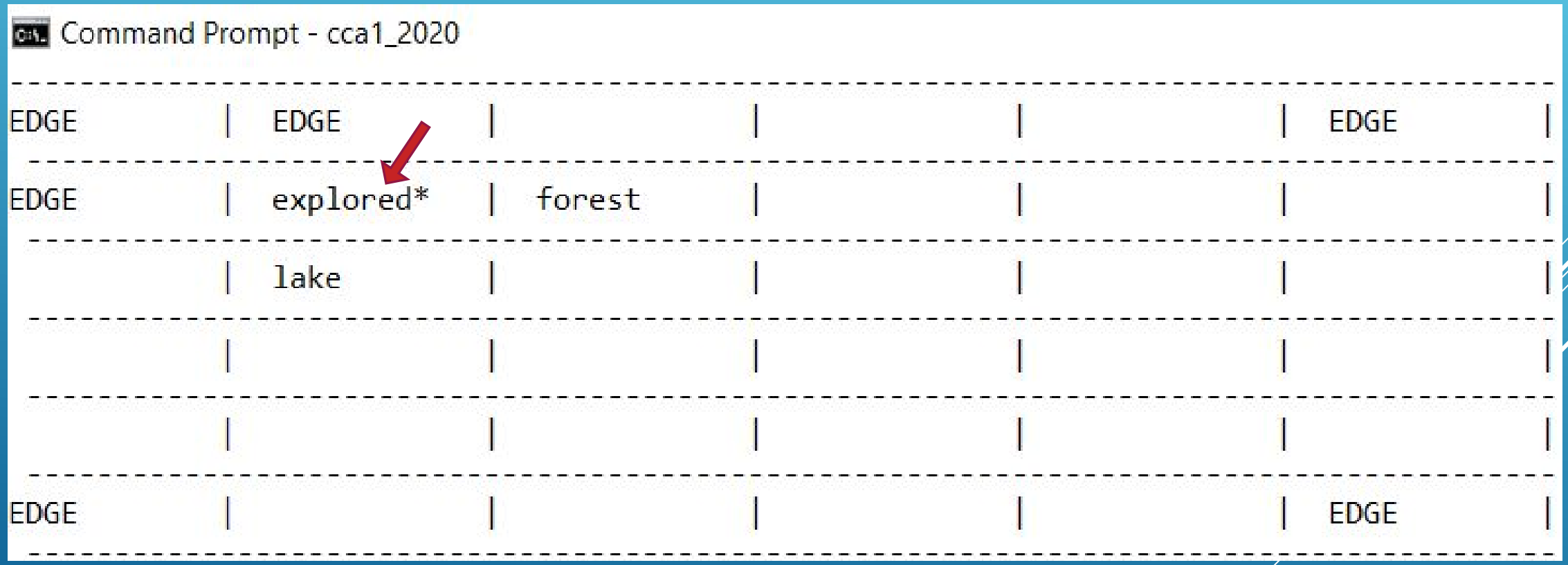
CCA1 builds up internal map from perceptions (and processing) in N, E, S, W directions



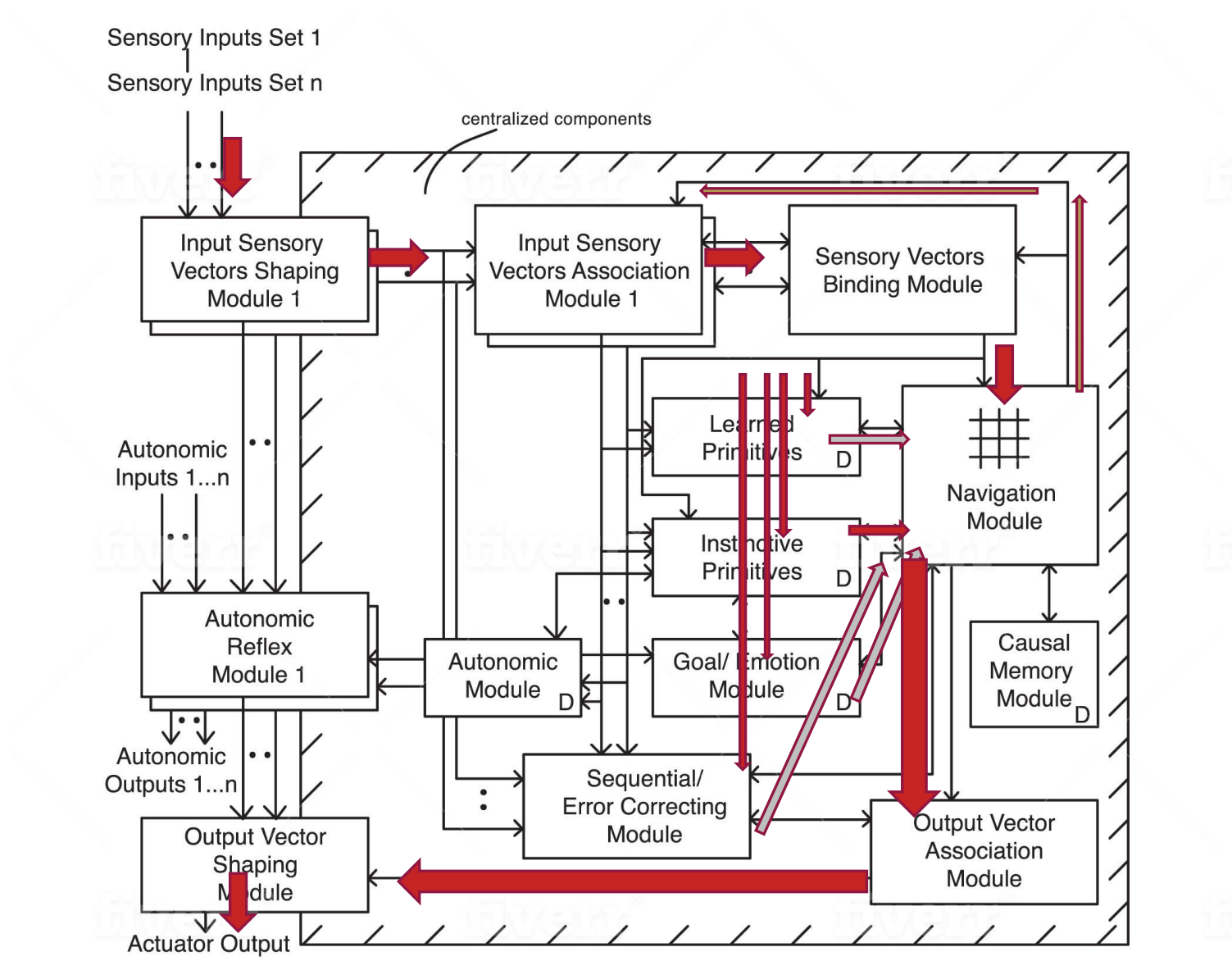
Lake (deep water) – Instinctive Primitive – do not go
Forest – Instinctive Primitive – no signal



CCA1 builds up internal map from perceptions (and processing) in N, E, S, W directions



Navigation to the East (to the forest square)



CCA1 moves East into 'forest' square

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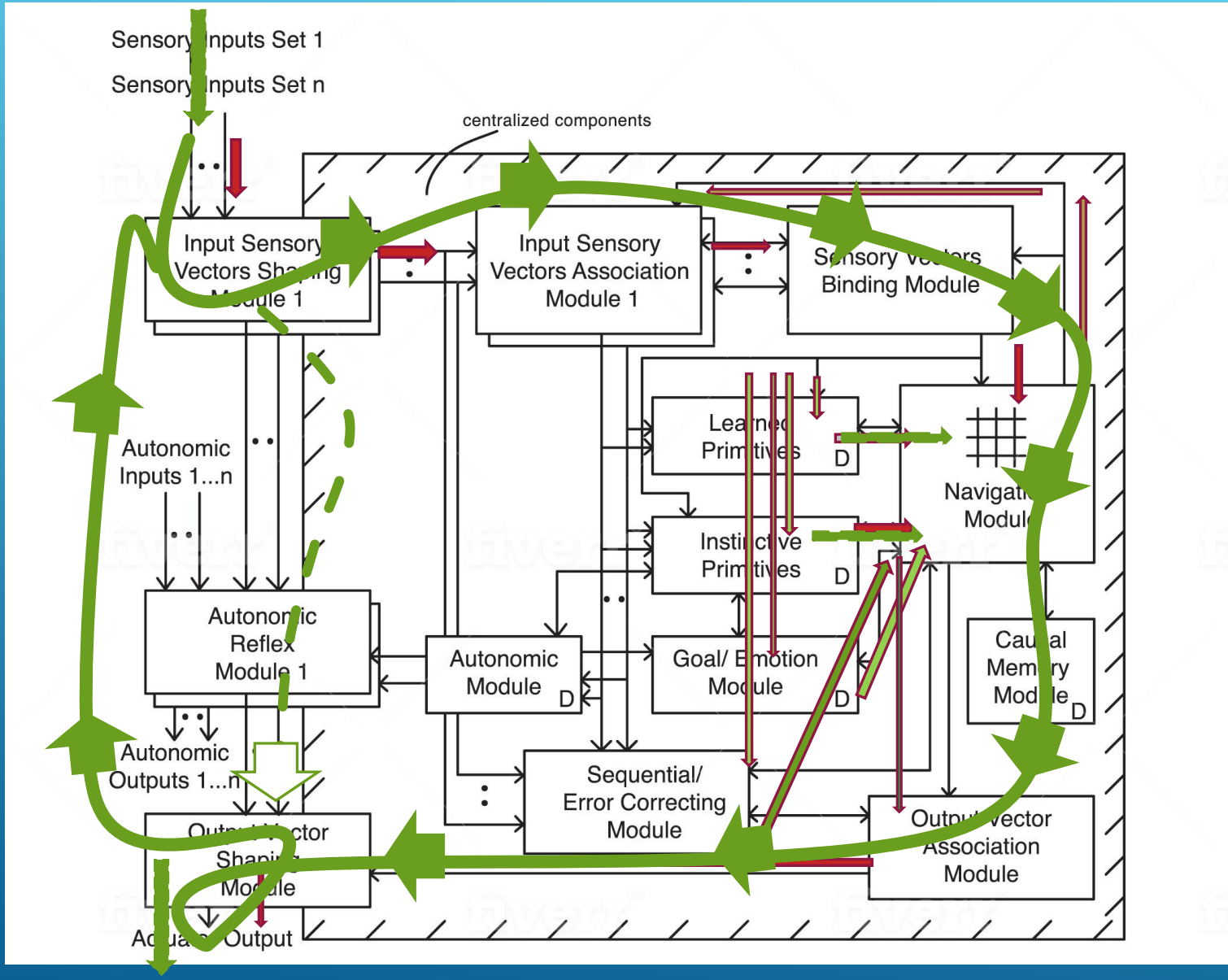
```
CCA1 moved from (1, 1)  1,2

Bird's-Eye View of Forest (CCA1 does not have this view)
-------------------------------------------------------------------------------
EDGE       |  EDGE       |  EDGE       |  EDGE       |  EDGE       |  EDGE       |
 ------------------------------------------------------------------------------
EDGE       |  forest     |  CCA1  *    |  sh_rvr     |  forest     |  EDGE       |
 ------------------------------------------------------------------------------
EDGE       |  lake       |  forest     |  forest     |  forest     |  EDGE       |
 ------------------------------------------------------------------------------
EDGE       |  forest     |  wtrfall    |  forest     |  forest     |  EDGE       |
 ------------------------------------------------------------------------------
EDGE       |  forest     |  hiker      |  forest     |  forest     |  EDGE       |
 ------------------------------------------------------------------------------
EDGE       |  EDGE       |  EDGE       |  EDGE       |  EDGE       |  EDGE       |
```

"Processing Cycles" repeat over and over again

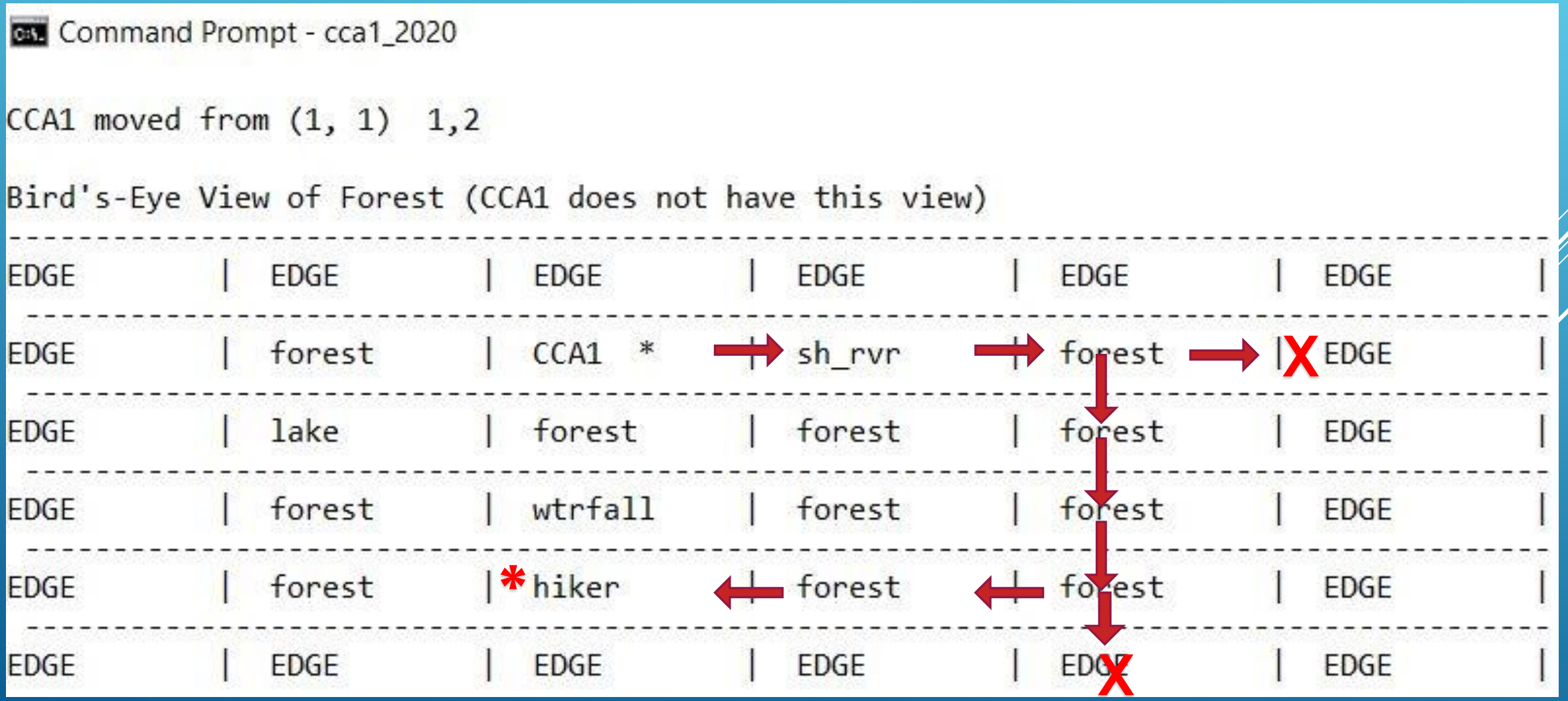


No Special Central Controlling Stored Program

No computer-like clock circuitry centrally controlling CCA1

Vectors propagated from circuit to circuit, and then the cycle is repeated

CCA1 eventually navigates to the hiker square, and rescues the lost hiker



Start new CCA1 simulation….

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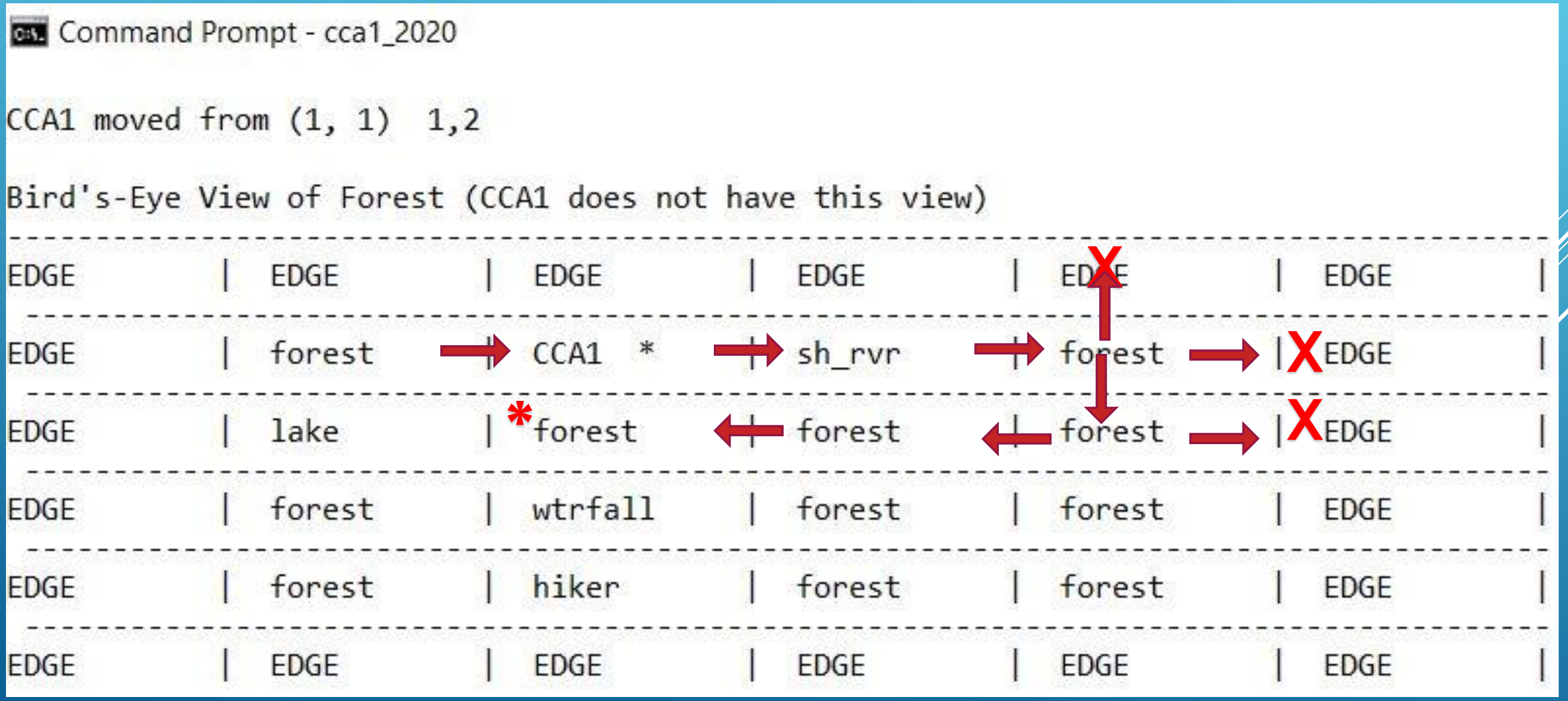
```
hiker position set to:  4 2

Bird's-Eye View of Forest (CCA1 does not have this view)
```

EDGE	EDGE	EDGE	EDGE	EDGE	EDGE
EDGE	CCA1 *	forest	sh_rvr	forest	EDGE
EDGE	lake	forest	forest	forest	EDGE
EDGE	forest	wtrfall	forest	forest	EDGE
EDGE	forest	hiker	forest	forest	EDGE
EDGE	EDGE	EDGE	EDGE	EDGE	EDGE

CCA1 moves to north of the waterfall square….



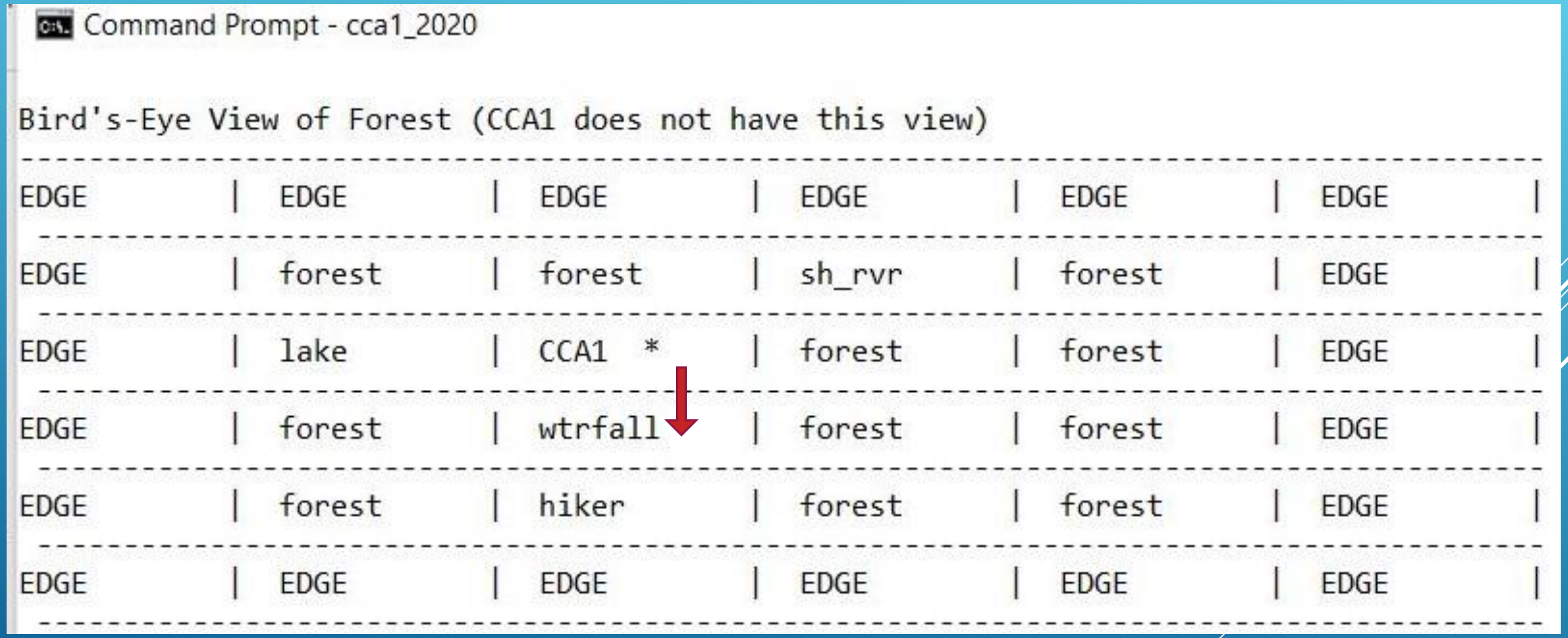
CCA1 has moved north of the waterfall square…

Command Prompt - cca1_2020

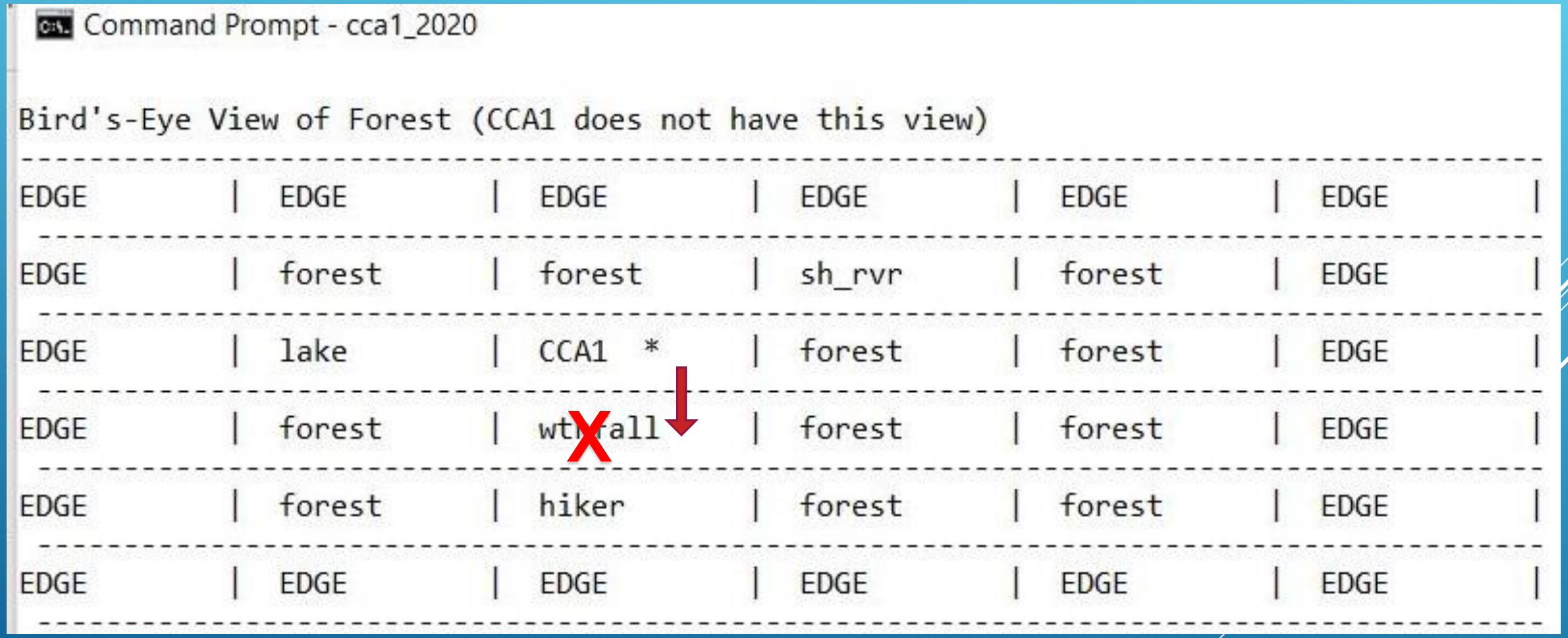
```
Bird's-Eye View of Forest (CCA1 does not have this view)
-------------------------------------------------------------------------------
EDGE       | EDGE       | EDGE       | EDGE       | EDGE       | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | forest     | sh_rvr     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | lake       | CCA1  *    | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | wtrfall    | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | hiker      | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | EDGE       | EDGE       | EDGE       | EDGE       | EDGE       |
-------------------------------------------------------------------------------
```

CCA1 has never seen a waterfall before…. just sees a river (noisy….fast flowing)…. and is generally able to cross rivers

S – sees fast noisy river (does not see cliff part) Able to cross shallow rivers, so moves South



CCA1 moves S (south) and is swept off cliff of waterfall and is damaged – mission ends

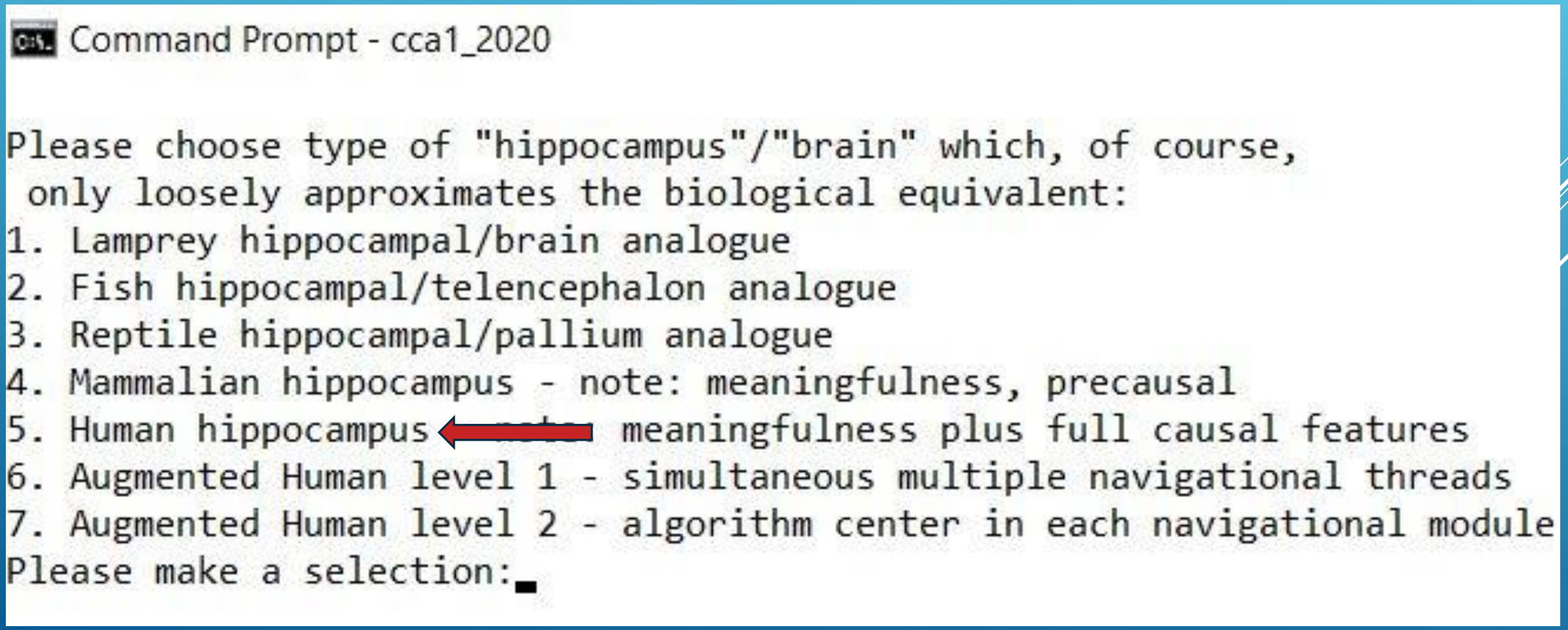


Failure of mission

Associative Learning Does Occur

-If repaired and it goes out into the forest on another mission
-Sees fast flowing river with much noise
-Triggers in Goal/Emotion Module and Learned Primitives Module not to go there
-Makes another choice for direction of move

-New Simulation
-Use full causal features of architecture



CCA1 must navigate to the lost hiker's square

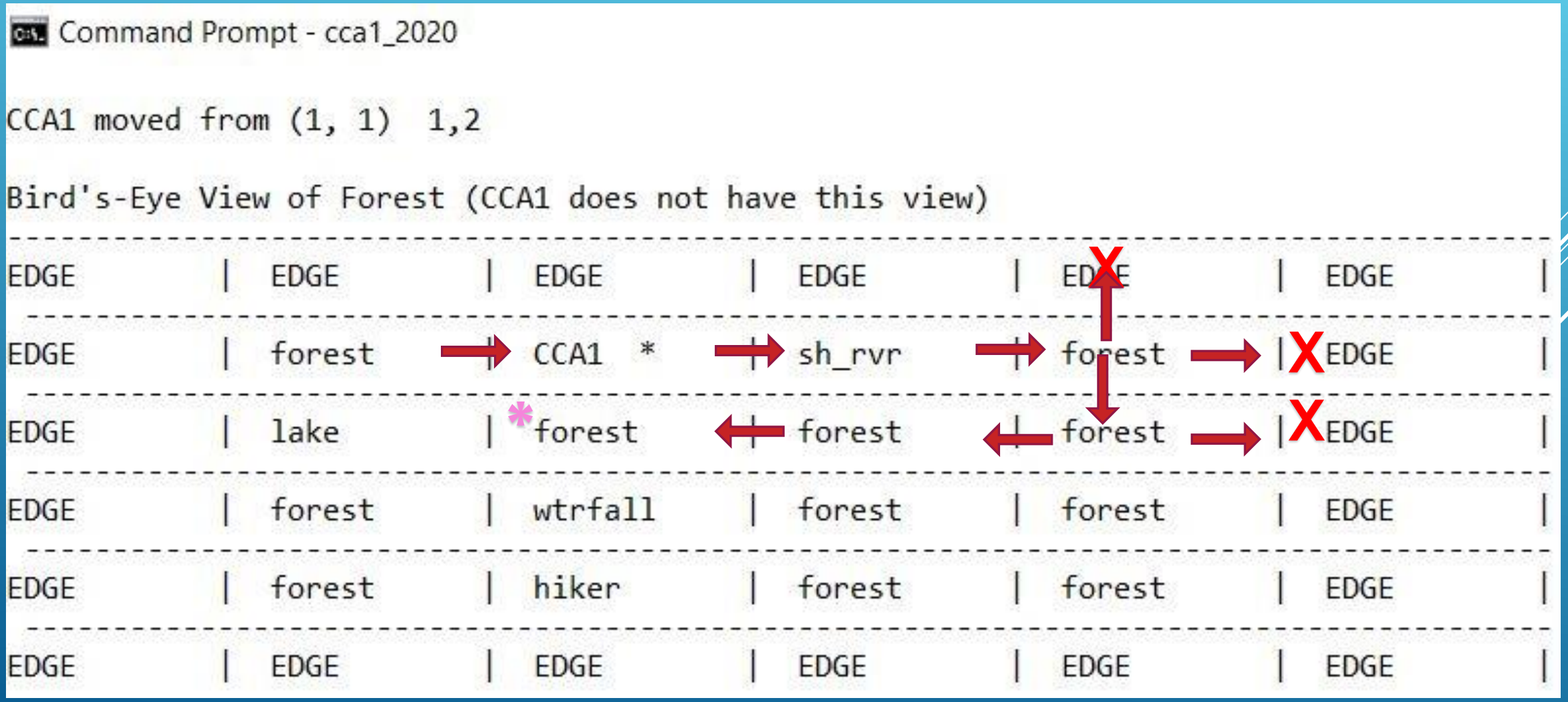
Command Prompt - cca1_2020

```
hiker position set to:  4 2

Bird's-Eye View of Forest (CCA1 does not have this view)
```

EDGE	EDGE	EDGE	EDGE	EDGE	EDGE
EDGE	CCA1 *	forest	sh_rvr	forest	EDGE
EDGE	lake	forest	forest	forest	EDGE
EDGE	forest	wtrfall	forest	forest	EDGE
EDGE	forest	hiker	forest	forest	EDGE
EDGE	EDGE	EDGE	EDGE	EDGE	EDGE

CCA1 moves to north of the waterfall square….

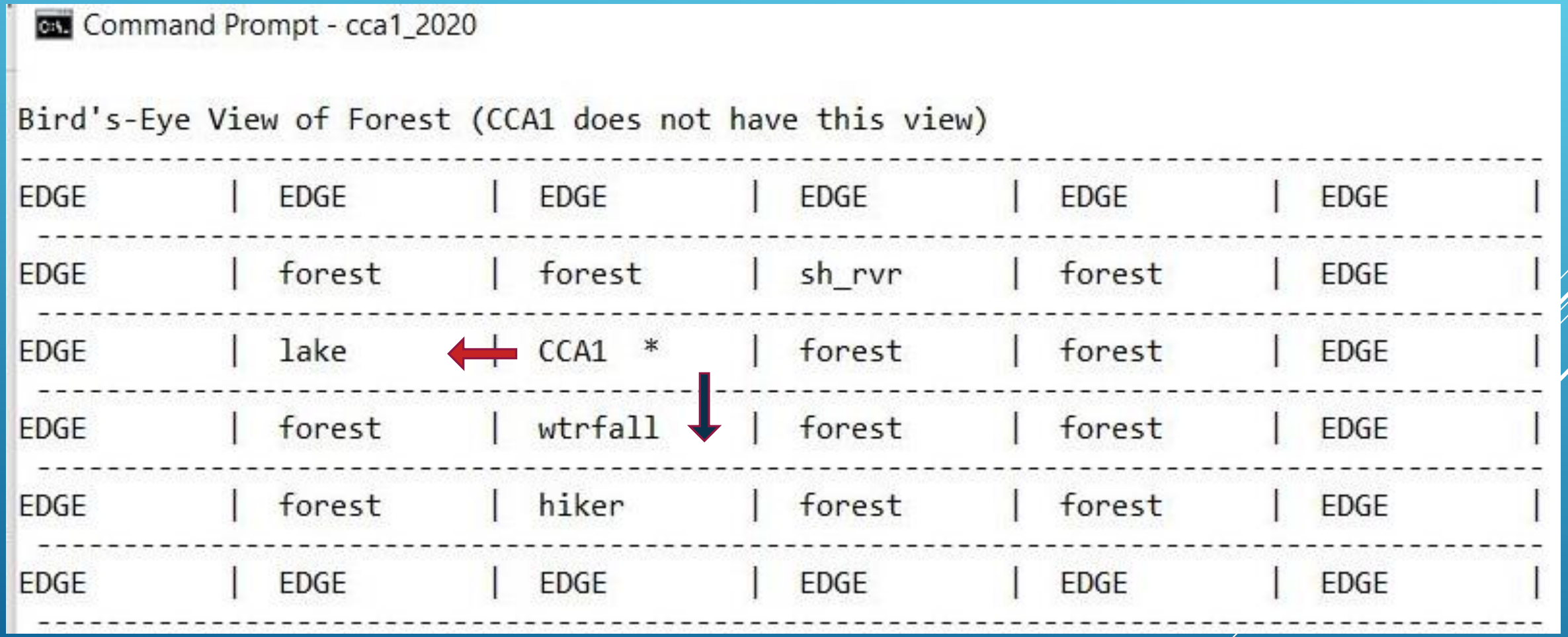


CCA1 has moved north of the waterfall square…

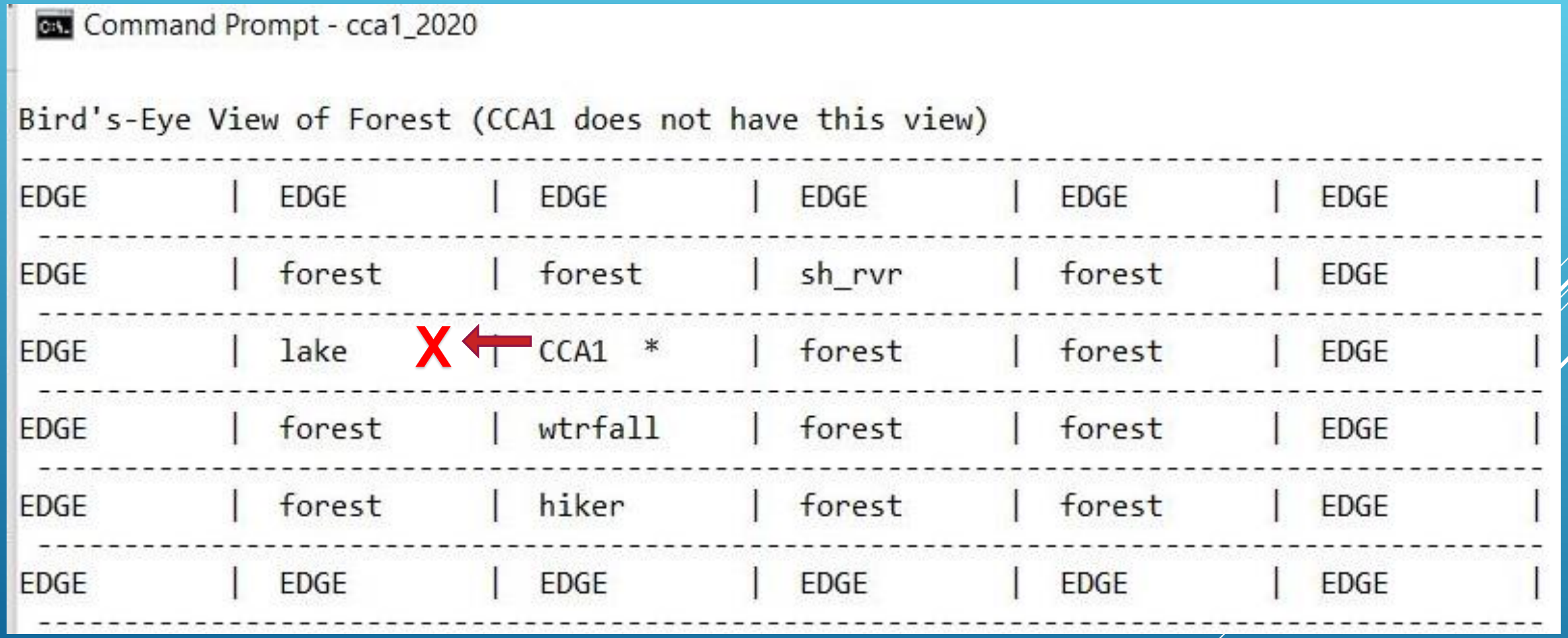
Command Prompt - cca1_2020

```
Bird's-Eye View of Forest (CCA1 does not have this view)
-------------------------------------------------------------------------------
EDGE       | EDGE       | EDGE       | EDGE       | EDGE       | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | forest     | sh_rvr     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | lake       | CCA1  *    | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | wtrfall    | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | forest     | hiker      | forest     | forest     | EDGE       |
-------------------------------------------------------------------------------
EDGE       | EDGE       | EDGE       | EDGE       | EDGE       | EDGE       |
-------------------------------------------------------------------------------
```

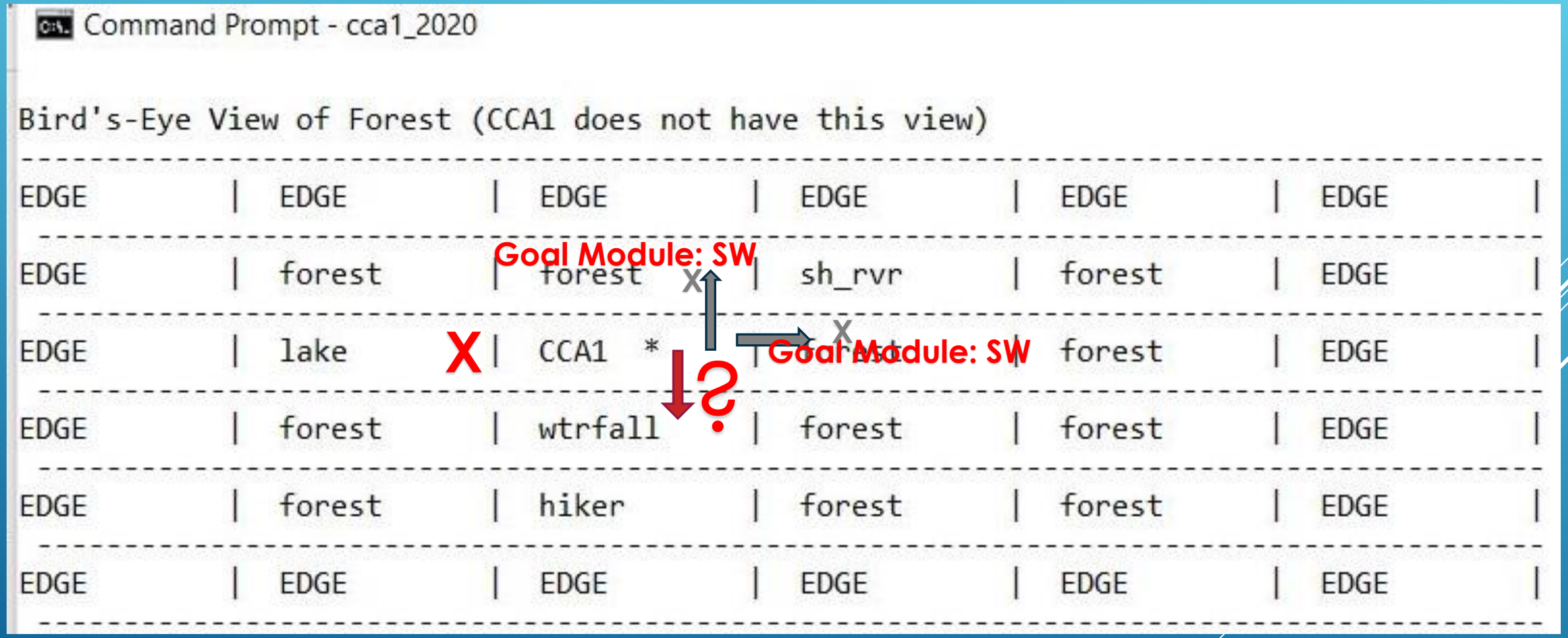
-Goal/Emotion Module favors trying W & S
-Ok to move W? (Then consider ok to move S?)



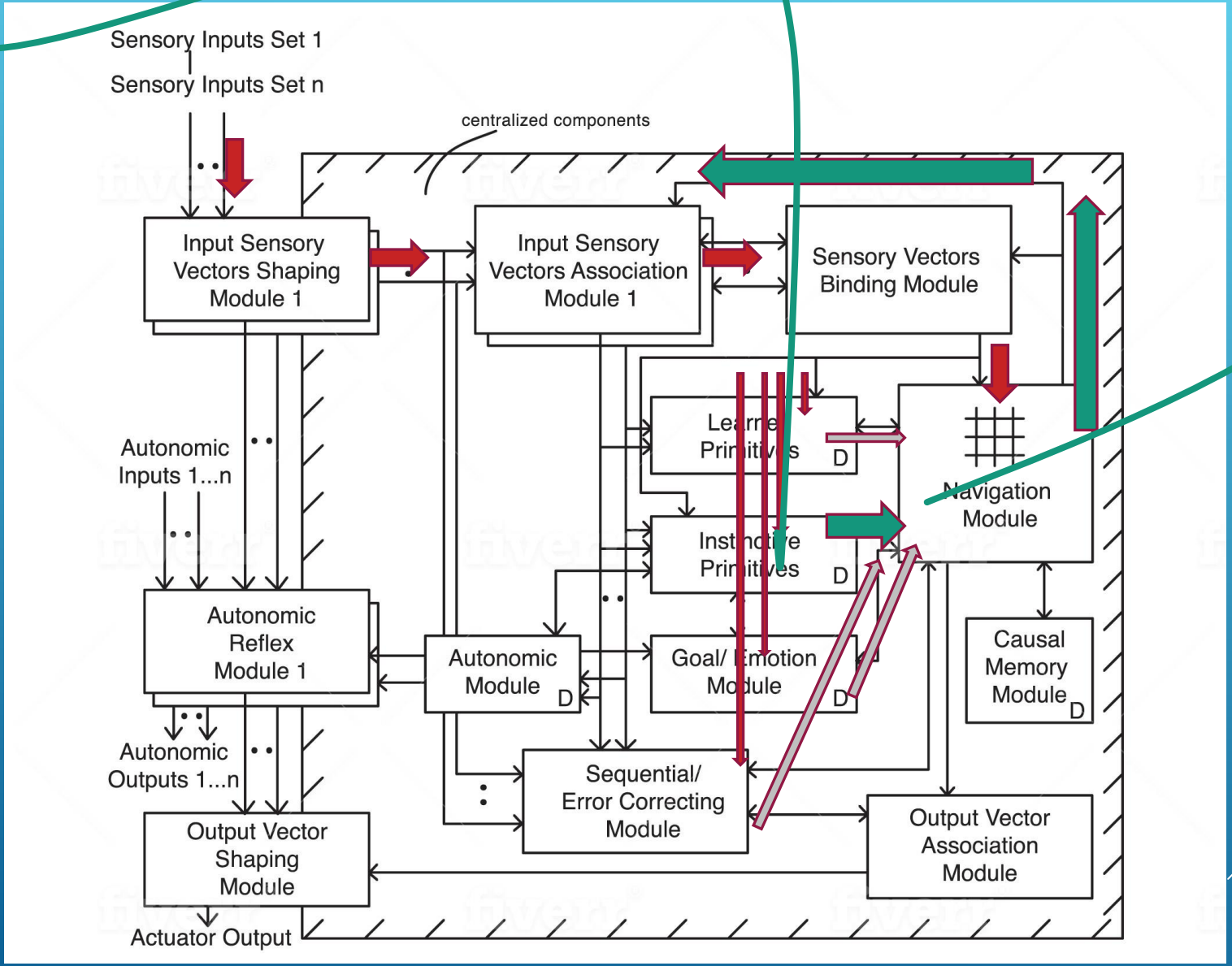
Instinctive Primitives rejects move W to lake



S – sees fast noisy river (does not see cliff part)



{“water”} + {“fast flow” + “noise”} → {“water” + “push”}

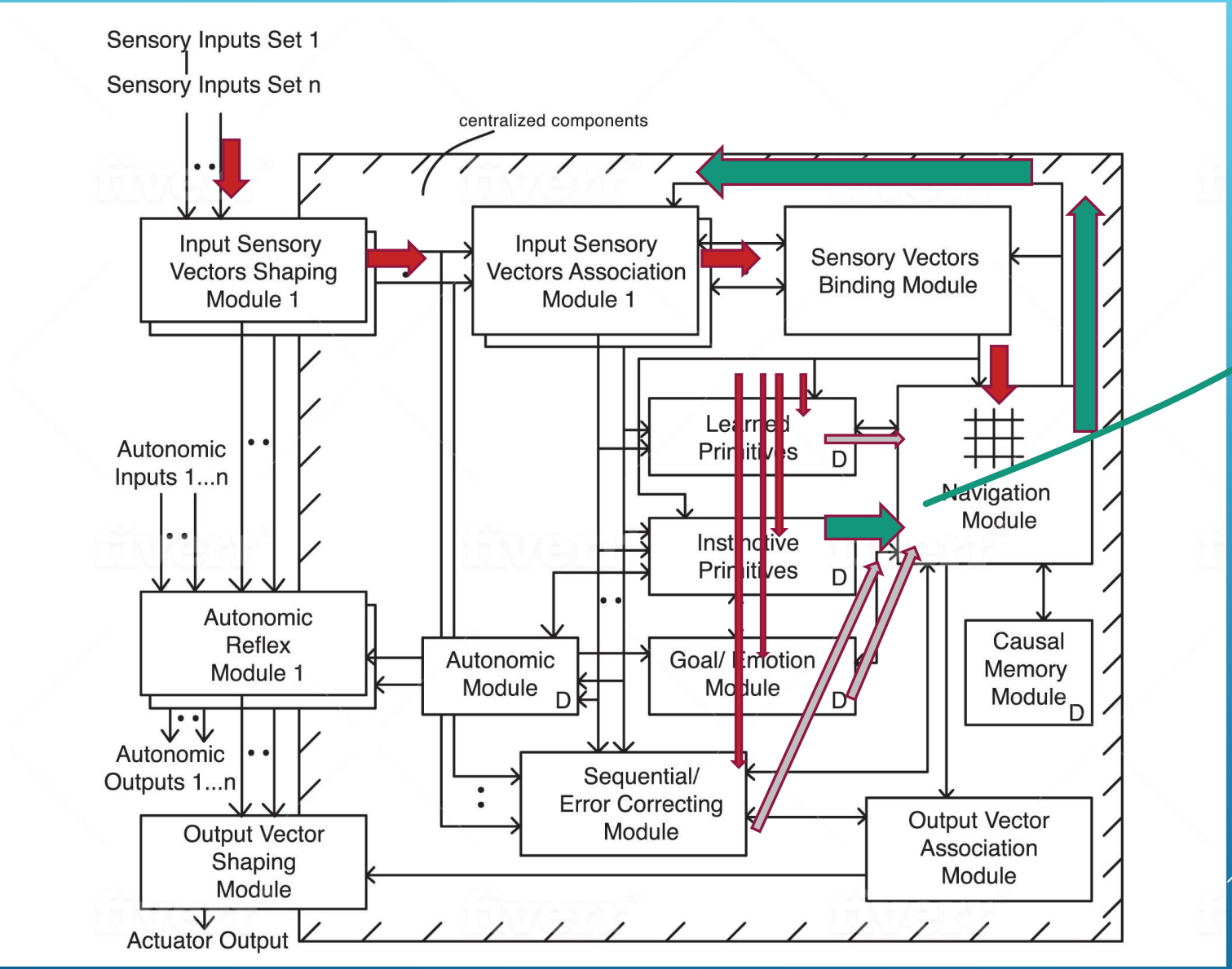


Temporary map → {“CCA1 under water”}

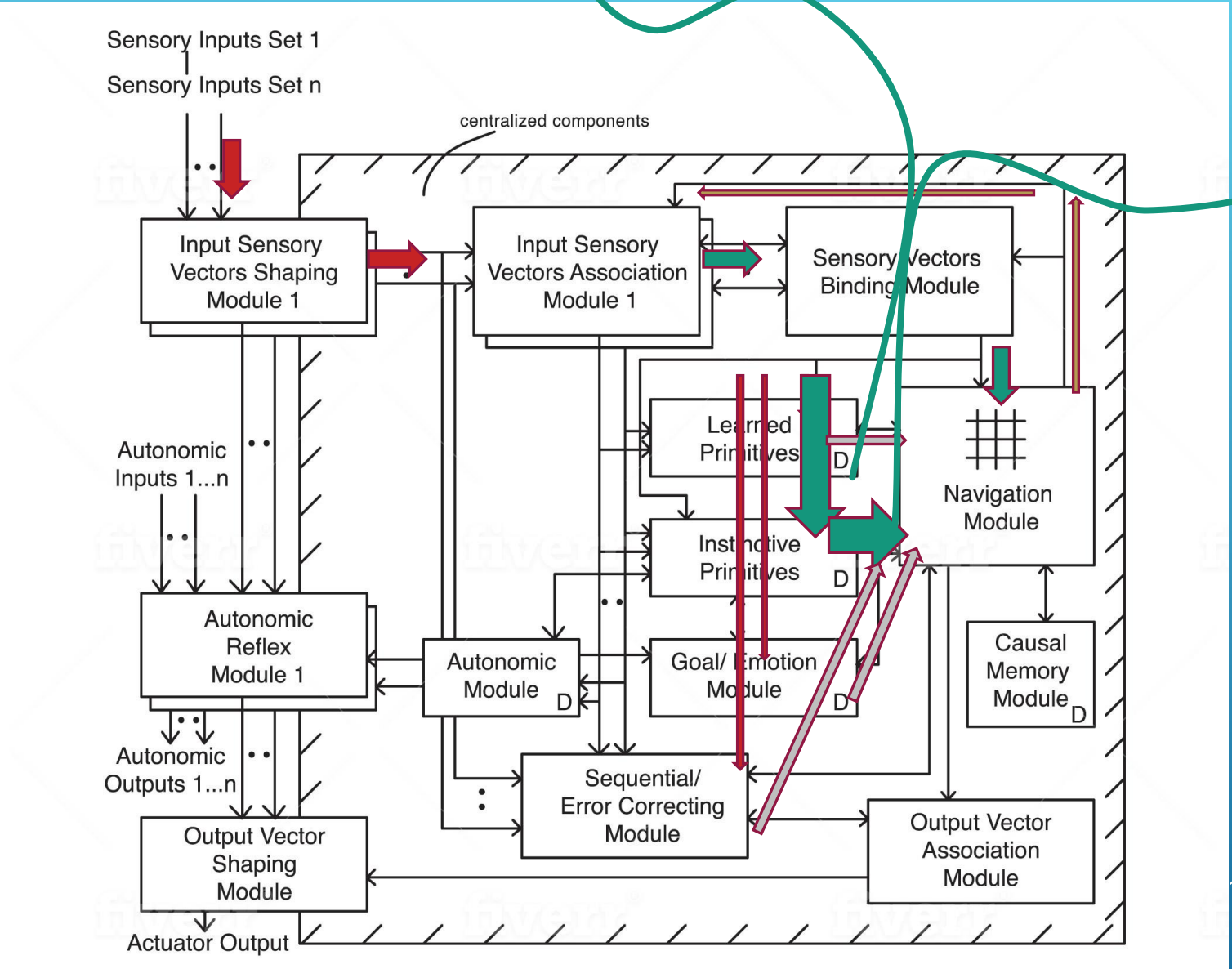
Command Prompt - cca1_2020

```
Internal Map From Stack
-------------------------------------------------------------------------------
air     | air     | air     | air     | air     | air     |
 -------------------------------------------------------------------------------
water   | water   | water   | water   | water   | water   |
 -------------------------------------------------------------------------------
water   | water   | water   | water   | water   | water   |
 -------------------------------------------------------------------------------
water   | water   | water   | CCA1  *   | water   | water   |
 -------------------------------------------------------------------------------
water   | water   | water   | water   | water   | water   |
 -------------------------------------------------------------------------------
water   | water   | water   | water   | water   | water   |
 -------------------------------------------------------------------------------
water   | water   | water   | water   | water   | water   |
 -------------------------------------------------------------------------------
```

{“CCA1 under water”} is fed back to sensory input module



{“CCA1 under water”}

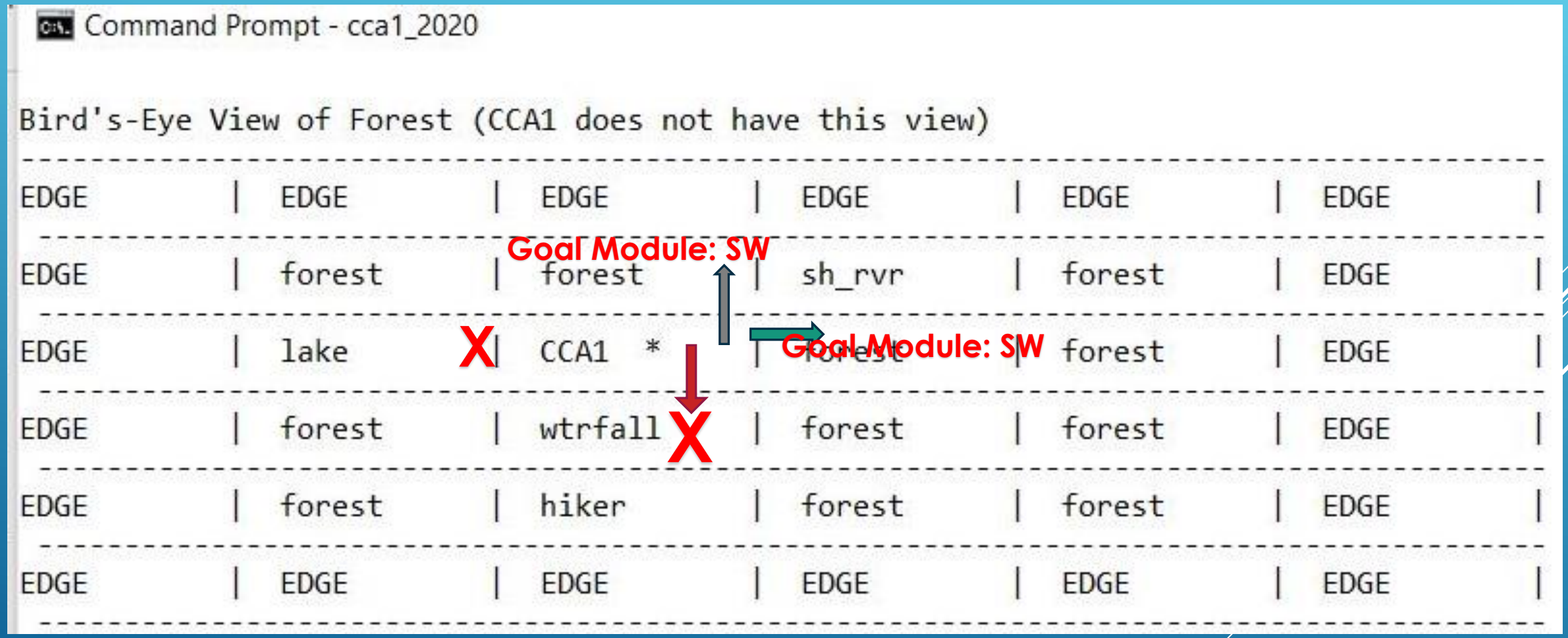


“do not go”

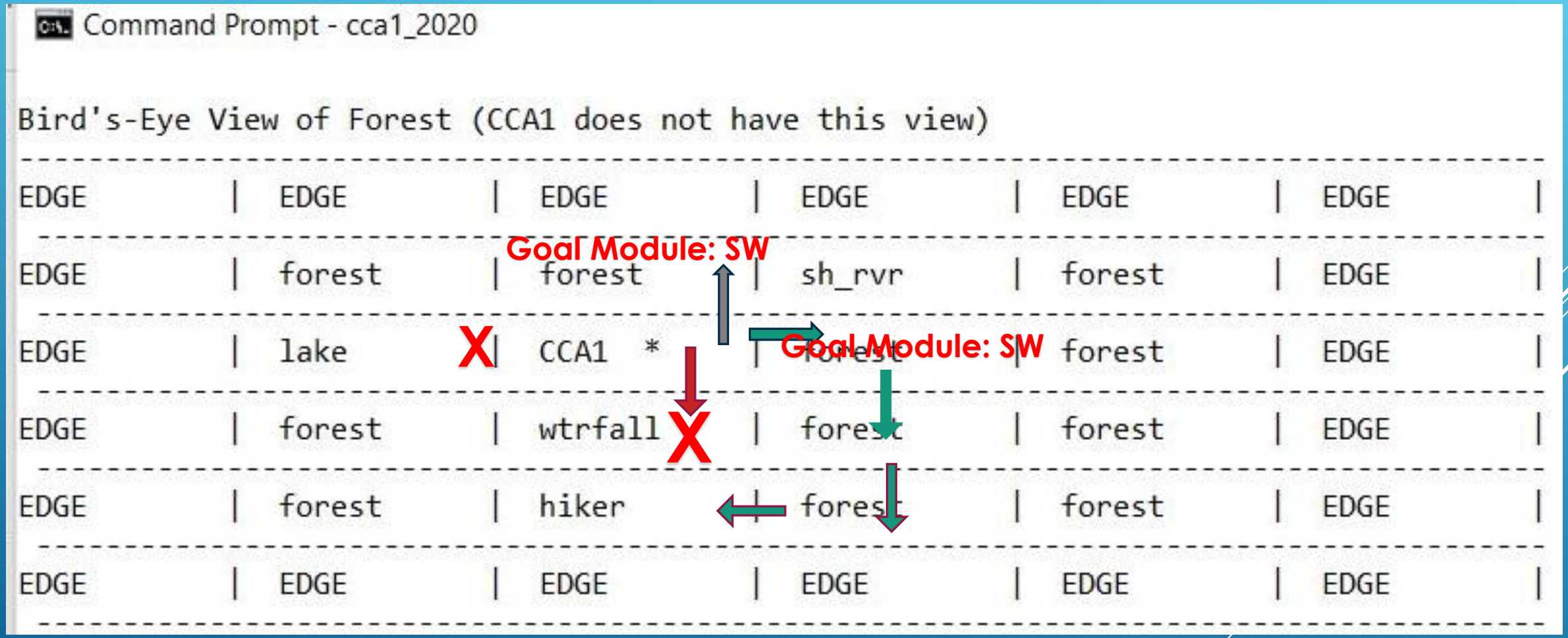
->retrieve previous temporary map

->do not go south

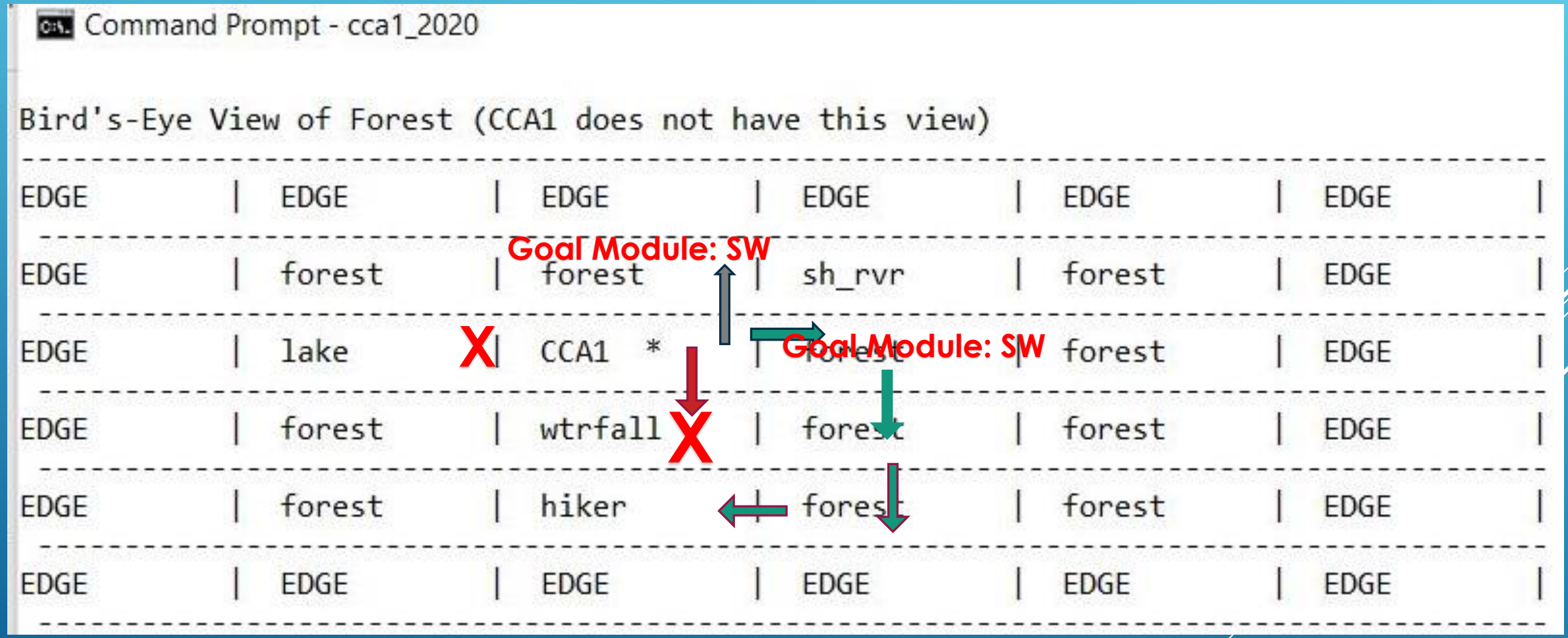
Do not go south – goes east even though bias from Goal Module to go south or west.



Continues south and then west…. and…. Rescues the lost hiker



Even though CCA1 had never seen a waterfall before, **it causally avoided this danger**

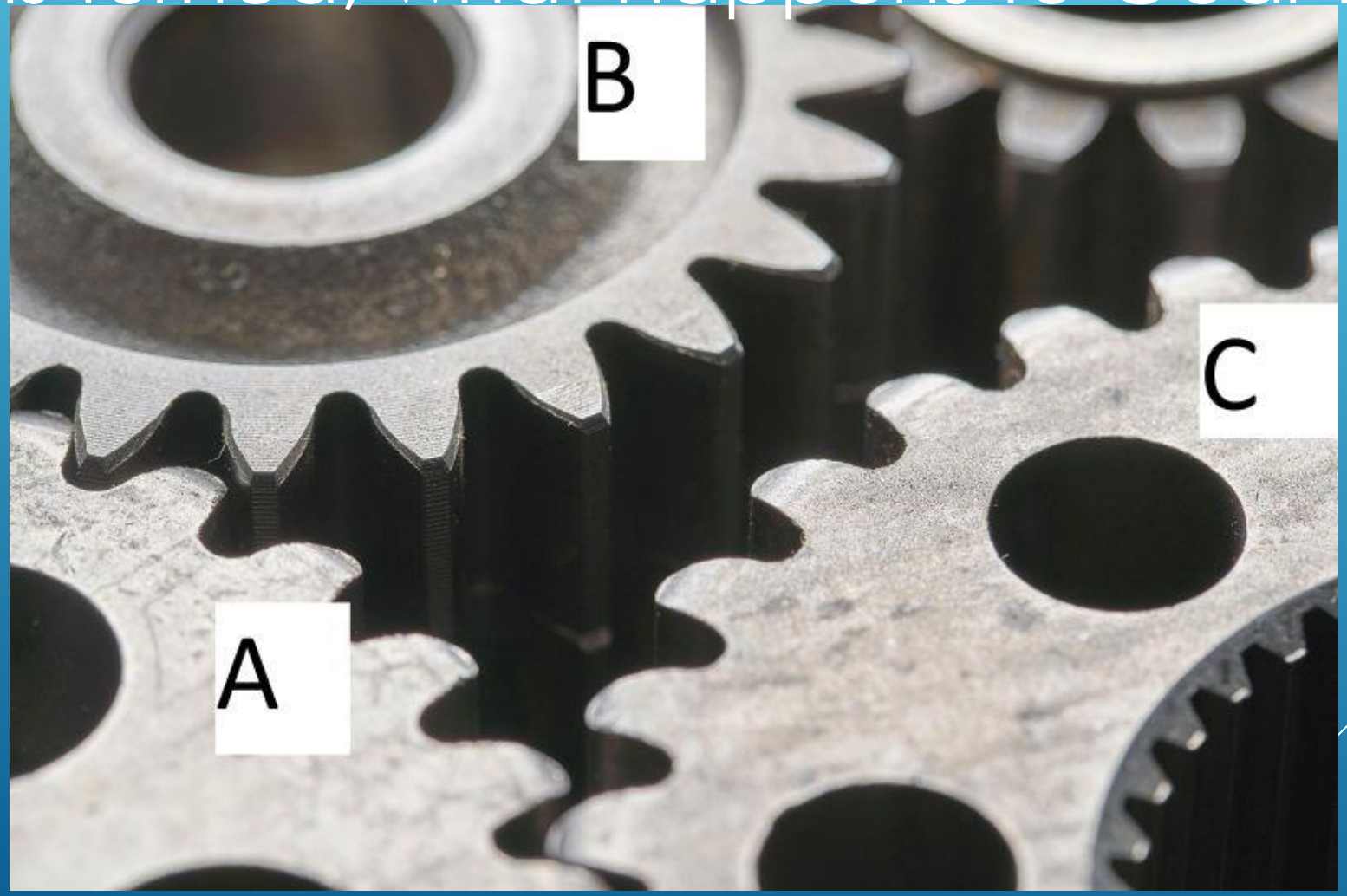


Causality emerges from the architecture

No central controlling stored program other than the repeating processing cycles of the CCA1

New simulation – CCA1 is inspecting a broken machine it has never seen before.

If Gear C is turned, what happens to Gear B?



Gear C is recognized and added to create a new temporary map

Command Prompt - cca1_2020

```
Internal Map From Stack
-------------------------------------------------------------------------------
air*        |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  *push      |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
C           |  A;moves    |  B;moves    |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
```

If push (turn) Gear C then Gear C moves (turns) and so will its specific neighbor move (turn)

Command Prompt - cca1_2020

Internal Map From Stack

air*	air	air	air	air	air
*push	air	air	air	air	air
C;moves	A;moves	air	air	air	air
air	air	air	air	air	air
air	air	air	air	air	air
air	air	air	air	air	air
air	air	air	air	air	air

Update with previous temporary map. New temporary map shows that if Gear C is moved (turned), then Gear B will move (turn)

Command Prompt - cca1_2020

```
Internal Map From Stack
-------------------------------------------------------------------------------
air*        |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
*push       |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
C;moves     |  A;moves    |  B;moves    |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
air         |  air        |  air        |  air        |  air        |  air        |
 ------------------------------------------------------------------------------
```

-Cannot fully repair a machine with 100's of parts by associations only (unless very common reasons for the breakdowns)

– even if only move a few parts there are millions and millions of combinations that need to be tried and learned by association ->simply not possible/practical

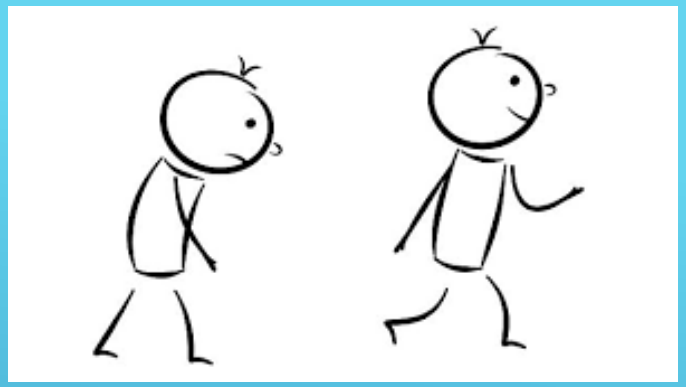
- Causality allows repairing a machine the CCA1 has never seen before.

⟹ **Causality emerges from the architecture**

Plausible evolutionary transition from Associative Behavior to a Causal Behavior

Small enhancements in circuitry allow this as shown in pre-causal to fully causal operation of the CCA1

Analogies



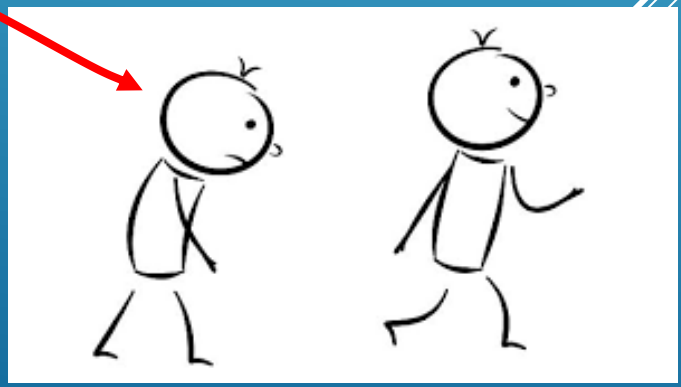
Should the CCA1 in our rescue example spend more time with person A or person B?

-Person B smiles a lot but is noisy, compared to Person A
-Who to chose?

→ Question for a philosopher!!

- Object A (i.e., person A) and object B (i.e., person B) are put onto a temporary map in the CCA1’s Navigation Module.
- Navigate to object B?
- Instinctive Primitives like smiling people == object B
- Object B is noisy →pulling up the previous temporary map it had—the river seemed safe but made much noise also, and was considered a danger.

- Intermediate results are fed back to the sensory input stages and processed again
- temporary maps are switched back again
- the noisy object B now is now associated with possible danger.
- There is a navigation output to navigate to object A (i.e., person A)



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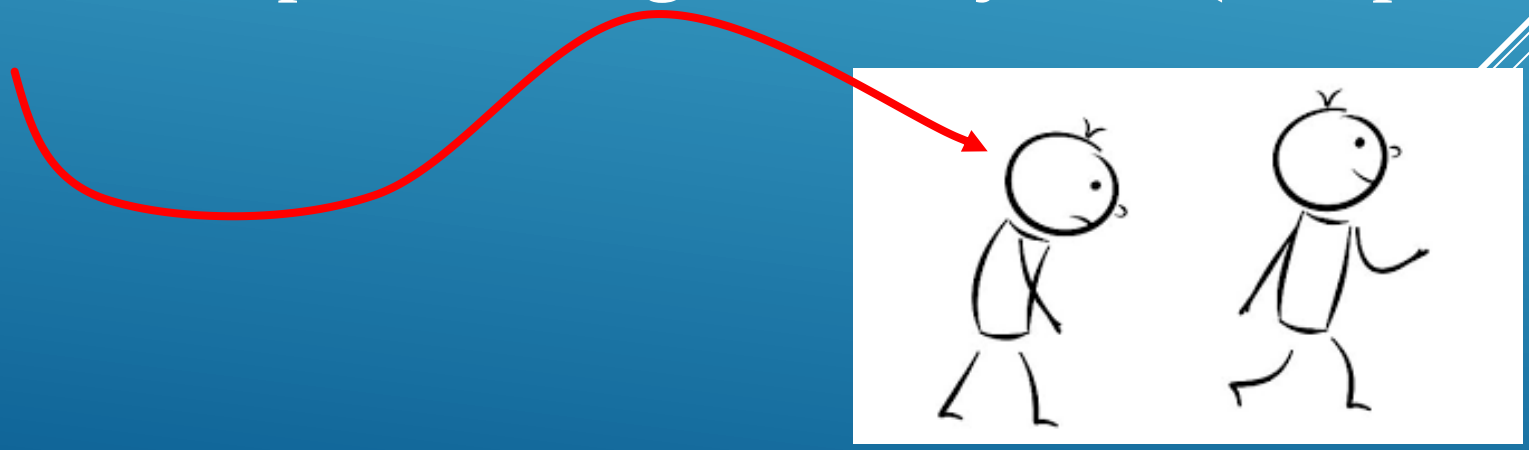
→CCA1's architecture and temporary maps, readily form and use analogies

There is a navigation output to navigate to object A (i.e., person A)

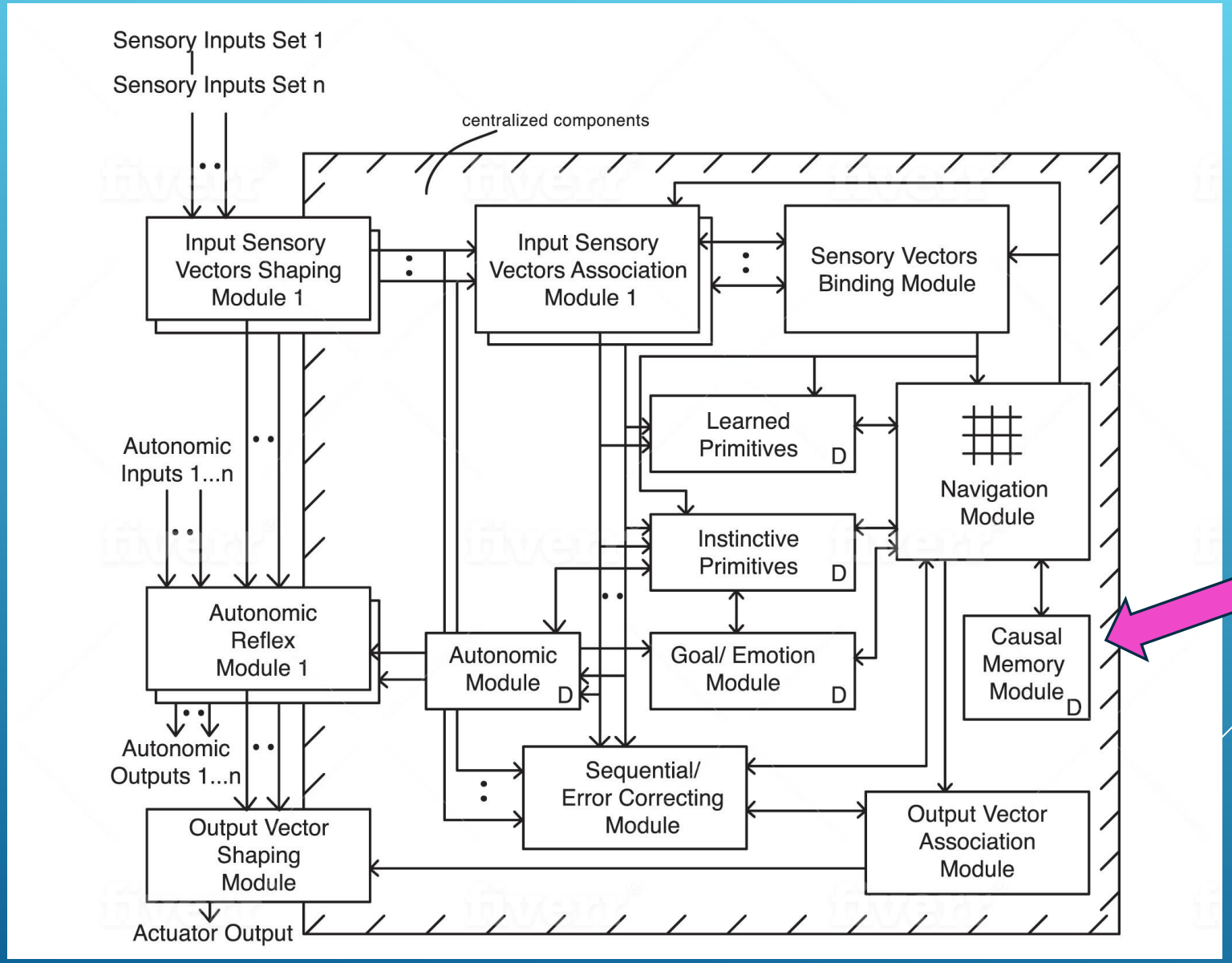


Explainability

After being used, ‘temporary maps’ are actually stored permanently in the Causal Memory portion of the Navigation Module

→Excellent explainability of pre-causal and causal actions

Causal Cognitive Architecture 1 (CCA1)



CCA1 Supports Schneider Psychosis Hypothesis

Schneider –BICA 2019:
-Imperfect functioning in going from precausal to full causal behavior (more complexity, feeding partial results back to sensory modules) can result in psychotic behavior (hallucinations, delusions and reduced cognition)

CCA1 -- Summary

- Allows causality to emerge from a system without any central controlling stored program (other than repeating sensory cycles)
- Tight integration of connectionist elements into a system capable of causal, symbolic operations

- High level cognitive processes emerge directly from the architecture
- Supports Schneider's psychosis hypothesis
- Provides a plausible pathway for the natural evolution of vertebrate brains
- Provides tool to explore pathways to AGI

*More detailed presentation of CCA1 to be presented at BICA*AI 2020 Virtual Conference*

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