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

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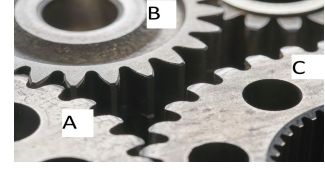


Figure 6.

ABSTRACT

The brain-inspired Causal Cognitive Architecture1 (CCA1) tightly integrates the sensory processing capabilities found in neural networks with many of the causal abilities found in human cognition. Sensory input vectors are processed by robust association circuitry and then propagated to a navigational temporary map. Instinctive and learned objects and procedures are applied to the same temporary map, with a resultant navigation signal obtained. Navigation can similarly be for the physical world as well as for a landscape of higher cognitive concepts. Causality emerges from the architecture, with good explainability. A simulation of the CCA1 controlling a search and rescue robot is presented.

INTRODUCTION

Artificial neural networks (ANNs) can recognize patterns and perform reinforcement learning at a human-like proficiency. However, compared to a four-year old child, in terms of logically and causally making sense of their environment or a problem at hand, especially if training examples are limited, they perform poorly (reference 1).

The biologically inspired Meaningful-Based Cognitive Architecture (MBCA) (reference 2) combines connectionist and symbolic elements.

The Causal Cognitive Architecture 1 (CCA1) presented here improves upon the MBCA with a more straightforward navigation-based logic system that works well with streams of vectors. Causal properties readily emerge from its architecture.

CCA1

An overview of the architecture of the CCA1 is shown in Figure 1. Input Sensory Vectors Association Modules contain a conventional neural network or a hierarchy of Hopfield-like Network units (HLNs) (reference 2), or equivalent, that can robustly associate an input sensory vector with other vectors within the CCA1.

The Navigation Module holds a temporary map of a small part of the perceived physical world, and on this small map are objects from the Sensory Vectors Binding Module, an object representing the CCA1 embodiment itself, and possible objects from the Instinctive Primitives Module and the Learned Primitives Module. Primitives Modules are triggered by input vectors, and affect objections and operations in the Navigation Module.

CCA1 RESCUER SIMULATION

The "CCA1" (= robot + controlling CCA1) must enter a grid world forest, and find and rescue a lost hiker.

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, pre-causal
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:

NON-CAUSAL MODE SIMULATION

The CCA1 builds up a map of the environment (Figure 2). The birds-eye view shown in Figure 3 is for the reader's benefit. The processed sensory input of 'lake' causes a 'do not go' Instinctive Primitive to the Navigation Module and there is no navigation to the south. However, a processed sensory input of 'forest' does not trigger such a primitive, and it moves to the east.

After a number of moves the CCA1 is at the square north of the 'waterfall' (Figure 4). The CCA1 has never seen a waterfall before. The Goal/Emotion Module wants moves to the south and west since previous north and east moves did not find the hiker. The CCA1 sees and hears the noisy water of the river, but not the cliff, of the waterfall. It is able to cross rivers, thus goes south, and is swept over the edge of the cliff. It is repaired and in the future a Learned Primitive of 'do not go' is triggered if there is a noisy river.

CAUSAL MODE SIMULATION

New simulation with full architecture used. CCA1 again navigates to the square above the waterfall (Figure 4). It has never seen a waterfall before. {'water'} + {'fast flow'} + {'noise'} triggers Instinctive Primitive {'water'} + {'push'} → Navigation Module. Can't process so feeds back to sensory stages.

In next processing cycle, the external sensory inputs ignored but {'water'} + {'push'} propagated from processed sensory stages, and triggers Instinctive Primitive to cause Navigation Module to bring up a new temporary map (Figure 5). Can't process further so feeds {'CCA1 under water'} back to sensory stages.

In the next processing cycle {'CCA1 under water'} propagates into architecture and triggers Instinctive Primitive 'do not go' → Navigation Module. The Navigation Module brings up previous temporary map and does not go south. Instead forced to go east and after a few more moves finds and rescues the hiker.

Even though CCA1 never saw a waterfall before, it causally avoided damage.

ARCHITECTURE

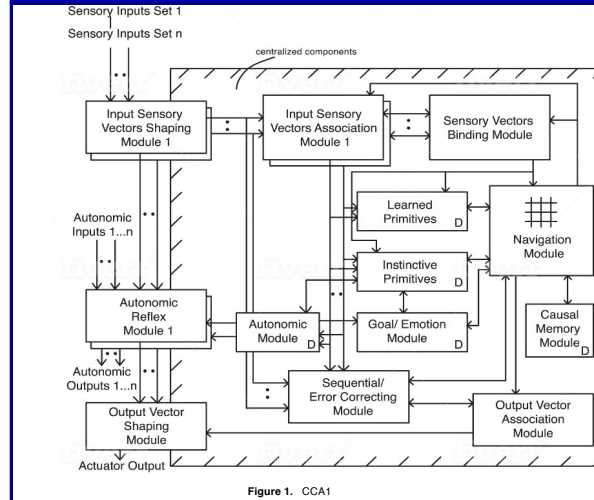


Figure 1. CCA1

EDGE	EDGE				EDGE
EDGE	explored*	forest			
	lake				
EDGE					EDGE

Figure 2. Internal Map of the CCA1

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

Figure 4. CCA1 Moves to Square North of Waterfall (Note: The CCA1 does not have this information but must build up its own internal temporary map)

OTHER EXAMPLES

-Analogies emerge from the architecture. Eg. Ask the CCA1 if it wants to spend time with person A or person B who is smiley but noisy. Instinctive Primitive positive for smiley but noisy causes temporary map of previous example to load into Navigation Module → danger → CCA1 chooses person A.

-CCA1 acting as repair robot. Machine with hundreds of broken parts. Never seen before. Similar operations of architecture allows prediction that if Gear C is turned then Gear B will turn (Figure 6), without the CCA1 ever experiencing this before.

CONCLUSIONS

The CCA1 can make cause and effect decisions for situations it has never seen before (eg, navigation to a waterfall square, eg, effect of moving one machine part on another part in the machine). Causality emerges not from a central controlling stored program (other than the basic repeating cycles of the architecture) but from the architecture.

Temporary maps are stored in the Causal Memory Module and provide good explainability for actions taken by the CCA1.

Higher cognitive concepts such as analogies emerge directly from the architecture of the CCA1.

REFERENCES

1. Waismeyer, A., Meltzoff, A.N., and Gopnik, A.: Causal learning from probabilistic events in 24-month-olds. Dev Science 18(1):175-182 (2015).
2. Schneider, H.: The Meaningful-Based Cognitive Architecture Model of Schizophrenia. Cognitive Systems Research 59:73-90 (2020).

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

Figure 3. Birds-Eye View of the Starting Positions of the CCA1 and the Lost Hiker

(Note: The CCA1 does not have this information but must build up its own internal temporary map)

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

Figure 5. {'water'} + {'push'} triggers in the Instinctive Primitives module a vector causing the Navigation Module to bring up a new temporary map – the CCA1 is pushed into water