Formalizing & Demonstrating Discontinuity
(in the context of PHP's "Darwin's Mistake")

Selmer Bringsjord
(with Naveen Sundar G • Christina Elmore • Matt Peveler)

Are Humans Rational?

11/11/19

Rensselaer AI and Reasoning Lab

But first, again, some logistics …

Logistics re. The Paper (version 1)…

Logistics re. The Paper (version 1)…

Keep in mind you can write on topics not yet covered in class!!
Let's visit the syllabus now to make sure you understand …

Logistics re. The Paper (version 1)…

Keep in mind you can write on topics not yet covered in class!!
Let's visit the syllabus now to make sure you understand …

Version 1 of Paper Due by Nov 25, 5pm. Turn in before, depending upon your plans for Thanksgiving week.

Logistics re. The Paper (version 1)…

Keep in mind you can write on topics not yet covered in class!!
Let's visit the syllabus now to make sure you understand …

Version 1 of Paper Due by Nov 25, 5pm. Turn in before, depending upon your plans for Thanksgiving week.

Submission must be in hard-copy form.

Logistics re. The Paper (version 1)…

Keep in mind you can write on topics not yet covered in class!!
Let's visit the syllabus now to make sure you understand …

Version 1 of Paper Due by Nov 25, 5pm. Turn in before, depending upon your plans for Thanksgiving week.

Submission must be in hard-copy form.

No more than 3 pages; double spaced; fourth page is for References; 12 pt font Times New Roman; margins at least 1" on all four sides; single-sided; use title page that has only title of paper, name, RIN, email address.

Logistics re. The Paper (version 1)…

Keep in mind you can write on topics not yet covered in class!!
Let's visit the syllabus now to make sure you understand …

Version 1 of Paper Due by Nov 25, 5pm. Turn in before, depending upon your plans for Thanksgiving week.

Submission must be in hard-copy form.

No more than 3 pages; double spaced; fourth page is for References; 12 pt font Times New Roman; margins at least 1" on all four sides; single-sided; use title page that has only title of paper, name, RIN, email address.

Structure:

My main thesis (T) is that ______.

Argument for T …

Anticipated one objection to your argument …

Rebuttal in response to the objection, in defense of your argument …

The Balderdash that is *Humans 3.0: The Upgrading of the Species*

Selmer Bringsjord
Nov 11 2019, 7pm
RPI; Room: Sage 3303
public invited

Here's an accurate encapsulation, put declaratively, of the book (H3.0) in question:

As a matter of mathematics, religious belief will disappear. Work will be obsolete, but economic well-being will be maximally high across Earth's human population; this will be enabled by AI toiling for us. Science will explain everything, including discovering the "patterns" that are us. With these patterns in our hands, we will be able to repeatedly "upload" to the physical substrate of our choosing, and thereby live forever. Then, by 2045, The Singularity will occur, the moment in time when machine intelligence exceeds human intelligence, and immediately thereafter explodes to higher and higher levels that infinitely exceed our own (relatively speaking) rodent-level one. Conveniently, we will merge with the machines so as to dodge being destroyed by them, and this "hybrid human-machine intelligence" will busy itself with [yada yada yada].

Unfortunately for Nowak (2015), author of H3.0, there is a slight problem: viz., every single claim here is but balderdash, at best. In this talk, I patiently explain this diagnosis, one bound, I know, to be emotionally disturbing to those who take such claptrap seriously.

The Balderdash that is *Humans 3.0: The Upgrading of the Species*

Selmer Bringsjord
Nov 11 2019, 7pm
RPI; Room: Sage 3303
public invited

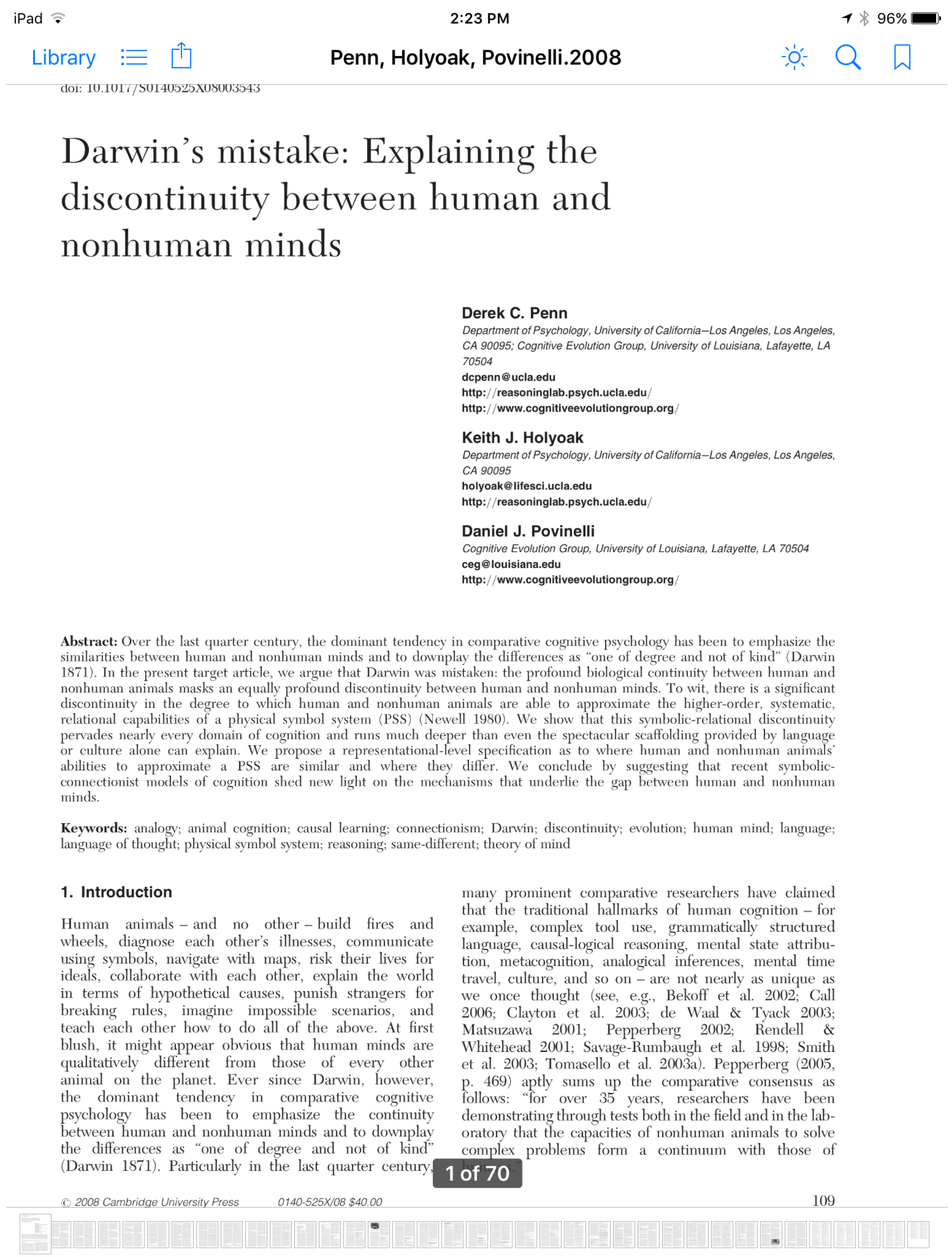
Here's an accurate encapsulation, put declaratively, of the book (H3.0) in question:

As a matter of mathematics, religious belief will disappear. Work will be obsolete, but economic well-being will be maximally high across Earth's human population; this will be enabled by AI toiling for us. Science will explain everything, including discovering the "patterns" that are us. With these patterns in our hands, we will be able to repeatedly "upload" to the physical substrate of our choosing, and thereby live forever. Then, by 2045, The Singularity will occur, the moment in time when machine intelligence exceeds human intelligence, and immediately thereafter explodes to higher and higher levels that infinitely exceed our own (relatively speaking) rodent-level one. Conveniently, we will merge with the machines so as to dodge being destroyed by them, and this "hybrid human-machine intelligence" will busy itself with [yada yada yada].

Unfortunately for Nowak (2015), author of H3.0, there is a slight problem: viz., every single claim here is but balderdash, at best. In this talk, I patiently explain this diagnosis, one bound, I know, to be emotionally disturbing to those who take such claptrap seriously.

The Paper for Today

The Paper for Today



doi: 10.1017/S0140525X08003543

Darwin's mistake: Explaining the discontinuity between human and nonhuman minds

Derek C. Penn
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095; Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
dcpenn@ucla.edu
http://reasoninglab.psych.ucla.edu/
http://www.cognitiveevolutiongroup.org/

Keith J. Holyoak
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095
holyoak@lifesci.ucla.edu
http://reasoninglab.psych.ucla.edu/

Daniel J. Povinelli
Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
ceg@louisiana.edu
http://www.cognitiveevolutiongroup.org/

Abstract: Over the last quarter century, the dominant tendency in comparative cognitive psychology has been to emphasize the similarities between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). In the present target article, we argue that Darwin was mistaken: the profound biological continuity between human and nonhuman animals masks an equally profound discontinuity between human and nonhuman minds. To wit, there is a significant discontinuity in the degree to which human and nonhuman animals are able to approximate the higher-order, systematic, relational capabilities of a physical symbol system (PSS) (Newell 1980). We show that this symbolic-relational discontinuity pervades nearly every domain of cognition and runs much deeper than even the spectacular scaffolding provided by language or culture alone can explain. We propose a representational-level specification as to where human and nonhuman animals' abilities to approximate a PSS are similar and where they differ. We conclude by suggesting that recent symbolic-connectionist models of cognition shed new light on the mechanisms that underlie the gap between human and nonhuman minds.

Keywords: analogy; animal cognition; causal learning; connectionism; Darwin; discontinuity; evolution; human mind; language; language of thought; physical symbol system; reasoning; same-different; theory of mind

1. Introduction

Human animals – and no other – build fires and wheels, diagnose each other's illnesses, communicate using symbols, navigate with maps, risk their lives for ideals, collaborate with each other, explain the world in terms of hypothetical causes, punish strangers for breaking rules, imagine impossible scenarios, and teach each other how to do all of the above. At first blush, it might appear obvious that human minds are qualitatively different from those of every other animal on the planet. Ever since Darwin, however, the dominant tendency in comparative cognitive psychology has been to emphasize the continuity between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). Particularly in the last quarter century, many prominent comparative researchers have claimed that the traditional hallmarks of human cognition – for example, complex tool use, grammatically structured language, causal-logical reasoning, mental state attribution, metacognition, analogical inferences, mental time travel, culture, and so on – are not nearly as unique as we once thought (see, e.g., Bekoff et al. 2002; Call 2006; Clayton et al. 2003; de Waal & Tyack 2003; Matsuzawa 2001; Pepperberg 2002; Rendell & Whitehead 2001; Savage-Rumbaugh et al. 1998; Smith et al. 2003; Tomasello et al. 2003a). Pepperberg (2005, p. 469) aptly sums up the comparative consensus as follows: "for over 35 years, researchers have been demonstrating through tests both in the field and in the laboratory that the capacities of nonhuman animals to solve complex problems form a continuum with those of

 0140-525X/08 $40.00

The Paper

iPad 2:23 PM 96%

Library Penn, Holyoak, Povinelli.2008

doi: 10.1017/S0140525X08003543

Darwin's mistake: Explaining the discontinuity between human and nonhuman minds

Derek C. Penn
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095; Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
dcpenn@ucla.edu
http://reasoninglab.psych.ucla.edu/
http://www.cognitiveevolutiongroup.org/

Keith J. Holyoak
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095
holyoak@lifesci.ucla.edu
http://reasoninglab.psych.ucla.edu/

Daniel J. Povinelli
Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
ceg@louisiana.edu
http://www.cognitiveevolutiongroup.org/

Abstract: Over the last quarter century, the dominant tendency in comparative cognitive psychology has been to emphasize the similarities between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). In the present target article, we argue that Darwin was mistaken: the profound biological continuity between human and nonhuman animals masks an equally profound discontinuity between human and nonhuman minds. To wit, there is a significant discontinuity in the degree to which human and nonhuman animals are able to approximate the higher-order, systematic, relational capabilities of a physical symbol system (PSS) (Newell 1980). We show that this symbolic-relational discontinuity pervades nearly every domain of cognition and runs much deeper than even the spectacular scaffolding provided by language or culture alone can explain. We propose a representational-level specification as to where human and nonhuman animals' abilities to approximate a PSS are similar and where they differ. We conclude by suggesting that recent symbolic-connectionist models of cognition shed new light on the mechanisms that underlie the gap between human and nonhuman minds.

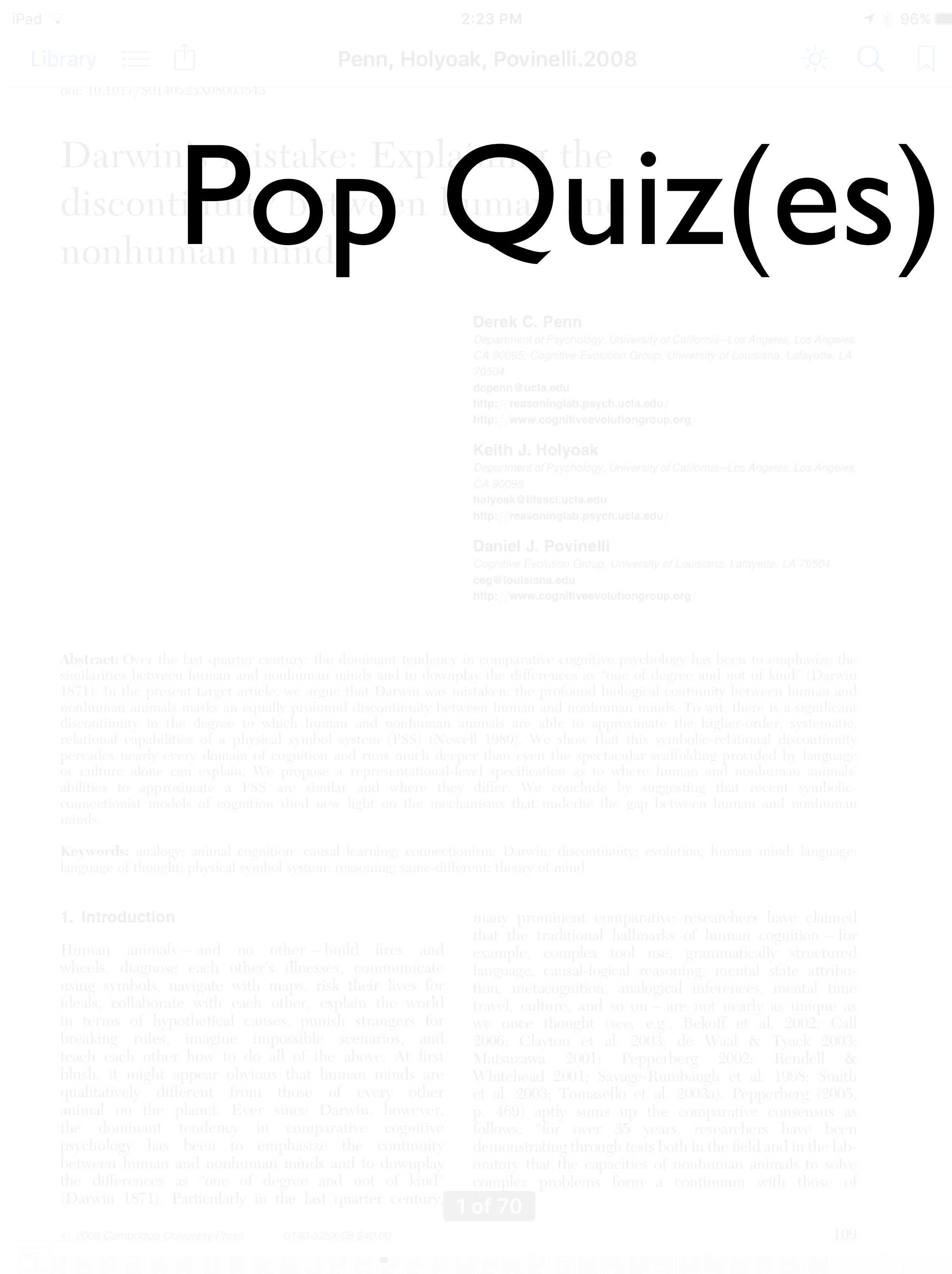
Keywords: analogy; animal cognition; causal learning; connectionism; Darwin; discontinuity; evolution; human mind; language; language of thought; physical symbol system; reasoning; same-different; theory of mind

1. Introduction

Human animals – and no other – build fires and wheels, diagnose each other's illnesses, communicate using symbols, navigate with maps, risk their lives for ideals, collaborate with each other, explain the world in terms of hypothetical causes, punish strangers for breaking rules, imagine impossible scenarios, and teach each other how to do all of the above. At first blush, it might appear obvious that human minds are qualitatively different from those of every other animal on the planet. Ever since Darwin, however, the dominant tendency in comparative cognitive psychology has been to emphasize the continuity between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). Particularly in the last quarter century, many prominent comparative researchers have claimed that the traditional hallmarks of human cognition – for example, complex tool use, grammatically structured language, causal-logical reasoning, mental state attribution, metacognition, analogical inferences, mental time travel, culture, and so on – are not nearly as unique as we once thought (see, e.g., Bekoff et al. 2002; Call 2006; Clayton et al. 2003; de Waal & Tyack 2003; Matsuzawa 2001; Pepperberg 2002; Rendell & Whitehead 2001; Savage-Rumbaugh et al. 1998; Smith et al. 2003; Tomasello et al. 2003a). Pepperberg (2005, p. 469) aptly sums up the comparative consensus as follows: "for over 35 years, researchers have been demonstrating through tests both in the field and in the laboratory that the capacities of nonhuman animals to solve complex problems form a continuum with those of

1 of 70

The Paper


iPad 2:23 PM 96%

Library Penn, Holyoak, Povinelli.2008

Darwin's mistake: Explaining the discontinuity between human and nonhuman minds

Derek C. Penn
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095; Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
dcpenn@ucla.edu
http://reasoninglab.psych.ucla.edu/
http://www.cognitiveevolutiongroup.org/

Keith J. Holyoak
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095
holyoak@lifesci.ucla.edu
http://reasoninglab.psych.ucla.edu/

Daniel J. Povinelli
Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
ceg@louisiana.edu
http://www.cognitiveevolutiongroup.org/

Abstract: Over the last quarter century, the dominant tendency in comparative cognitive psychology has been to emphasize the similarities between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). In the present target article, we argue that Darwin was mistaken: the profound biological continuity between human and nonhuman animals masks an equally profound discontinuity between human and nonhuman minds. To wit, there is a significant discontinuity in the degree to which human and nonhuman animals are able to approximate the higher-order, systematic, relational capabilities of a physical symbol system (PSS) (Newell 1980). We show that this symbolic-relational discontinuity pervades nearly every domain of cognition and runs much deeper than even the spectacular scaffolding provided by language or culture alone can explain. We propose a representational-level specification as to where human and nonhuman animals' abilities to approximate a PSS are similar and where they differ. We conclude by suggesting that recent symbolic-connectionist models of cognition shed new light on the mechanisms that underlie the gap between human and nonhuman minds.

Keywords: analogy; animal cognition; causal learning; connectionism; Darwin; discontinuity; evolution; human mind; language; language of thought; physical symbol system; reasoning; same-different; theory of mind

1. Introduction

Human animals – and no other – build fires and wheels, diagnose each other's illnesses, communicate using symbols, navigate with maps, risk their lives for ideals, collaborate with each other, explain the world in terms of hypothetical causes, punish strangers for breaking rules, imagine impossible scenarios, and teach each other how to do all of the above. At first blush, it might appear obvious that human minds are qualitatively different from those of every other animal on the planet. Ever since Darwin, however, the dominant tendency in comparative cognitive psychology has been to emphasize the continuity between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). Particularly in the last quarter century, many prominent comparative researchers have claimed that the traditional hallmarks of human cognition – for example, complex tool use, grammatically structured language, causal-logical reasoning, mental state attribution, metacognition, analogical inferences, mental time travel, culture, and so on – are not nearly as unique as we once thought (see, e.g., Bekoff et al. 2002; Call 2006; Clayton et al. 2003; de Waal & Tyack 2003; Matsuzawa 2001; Pepperberg 2002; Rendell & Whitehead 2001; Savage-Rumbaugh et al. 1998; Smith et al. 2003; Tomasello et al. 2003a). Pepperberg (2005, p. 469) aptly sums up the comparative consensus as follows: "for over 35 years, researchers have been demonstrating through tests both in the field and in the laboratory that the capacities of nonhuman animals to solve complex problems form a continuum with those of

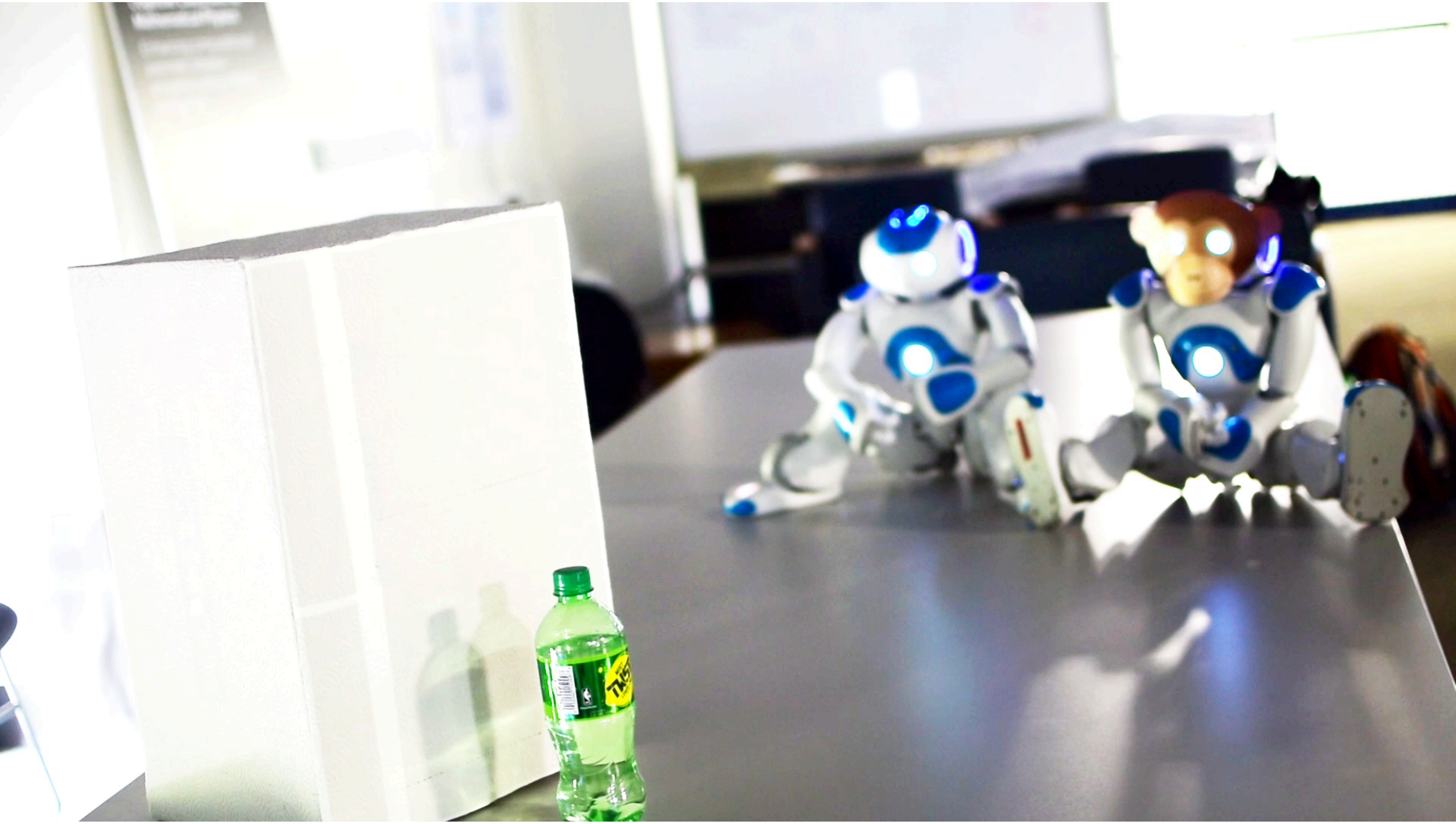
1 of 70

Pop Quiz(es)

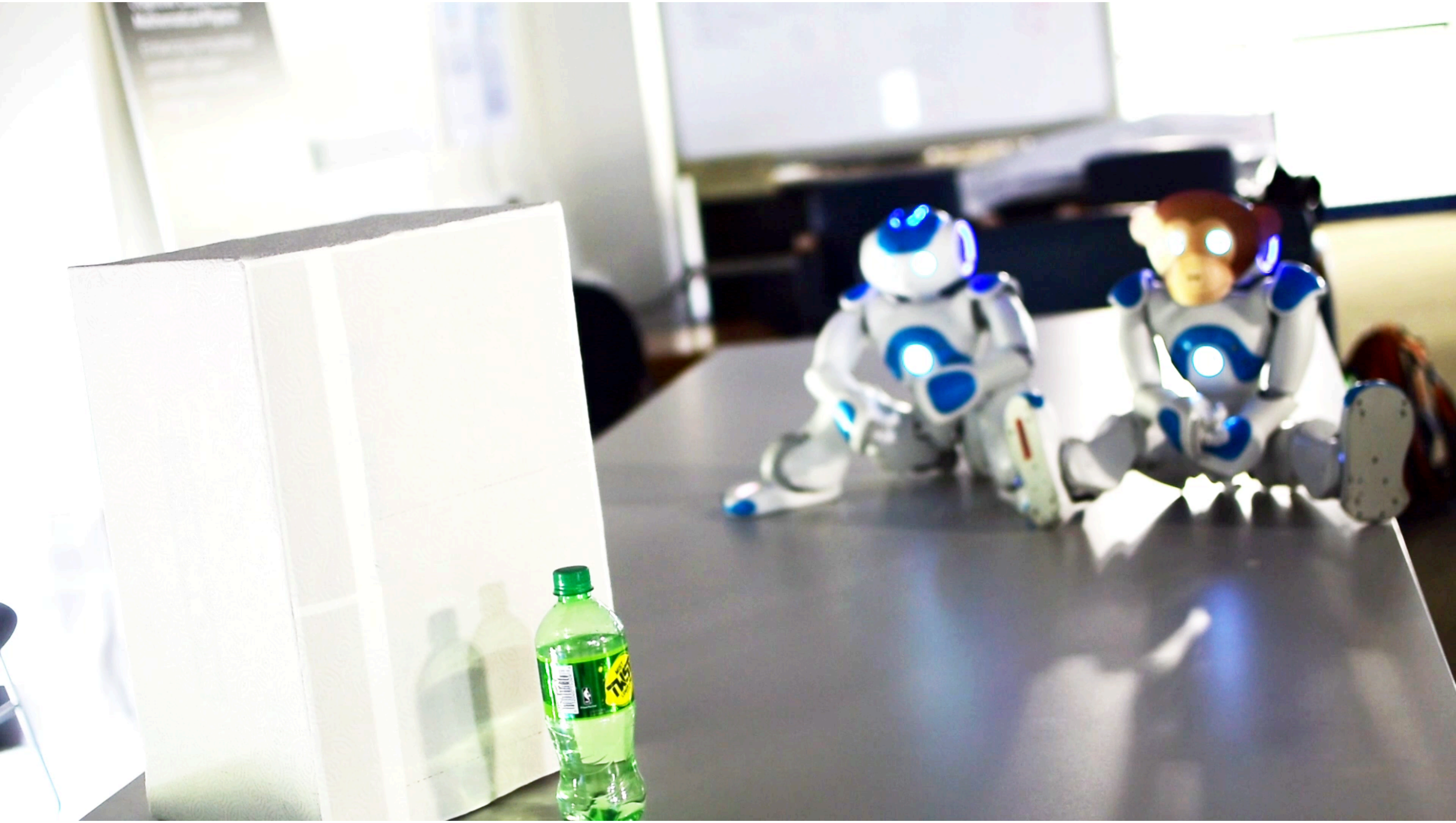
Pop Quiz(es)

What task, given to chimpanzees, involves soft drinks and is claimed by PHP to beyond these animals?

Learning by Analogical Reasoning?



Learning by Analogical Reasoning?



2

The Paper

iPad 2:23 PM 96%

Library Penn, Holyoak, Povinelli.2008

doi: 10.1017/S0140525X08003543

Darwin's mistake: Explaining the discontinuity between human and nonhuman minds

Derek C. Penn
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095; Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
dcpenn@ucla.edu
http://reasoninglab.psych.ucla.edu/
http://www.cognitiveevolutiongroup.org/

Keith J. Holyoak
Department of Psychology, University of California–Los Angeles, Los Angeles, CA 90095
holyoak@lifesci.ucla.edu
http://reasoninglab.psych.ucla.edu/

Daniel J. Povinelli
Cognitive Evolution Group, University of Louisiana, Lafayette, LA 70504
ceg@louisiana.edu
http://www.cognitiveevolutiongroup.org/

Abstract: Over the last quarter century, the dominant tendency in comparative cognitive psychology has been to emphasize the similarities between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). In the present target article, we argue that Darwin was mistaken: the profound biological continuity between human and nonhuman animals masks an equally profound discontinuity between human and nonhuman minds. To wit, there is a significant discontinuity in the degree to which human and nonhuman animals are able to approximate the higher-order, systematic, relational capabilities of a physical symbol system (PSS) (Newell 1980). We show that this symbolic-relational discontinuity pervades nearly every domain of cognition and runs much deeper than even the spectacular scaffolding provided by language or culture alone can explain. We propose a representational-level specification as to where human and nonhuman animals' abilities to approximate a PSS are similar and where they differ. We conclude by suggesting that recent symbolic-connectionist models of cognition shed new light on the mechanisms that underlie the gap between human and nonhuman minds.

Keywords: analogy; animal cognition; causal learning; connectionism; Darwin; discontinuity; evolution; human mind; language; language of thought; physical symbol system; reasoning; same-different; theory of mind

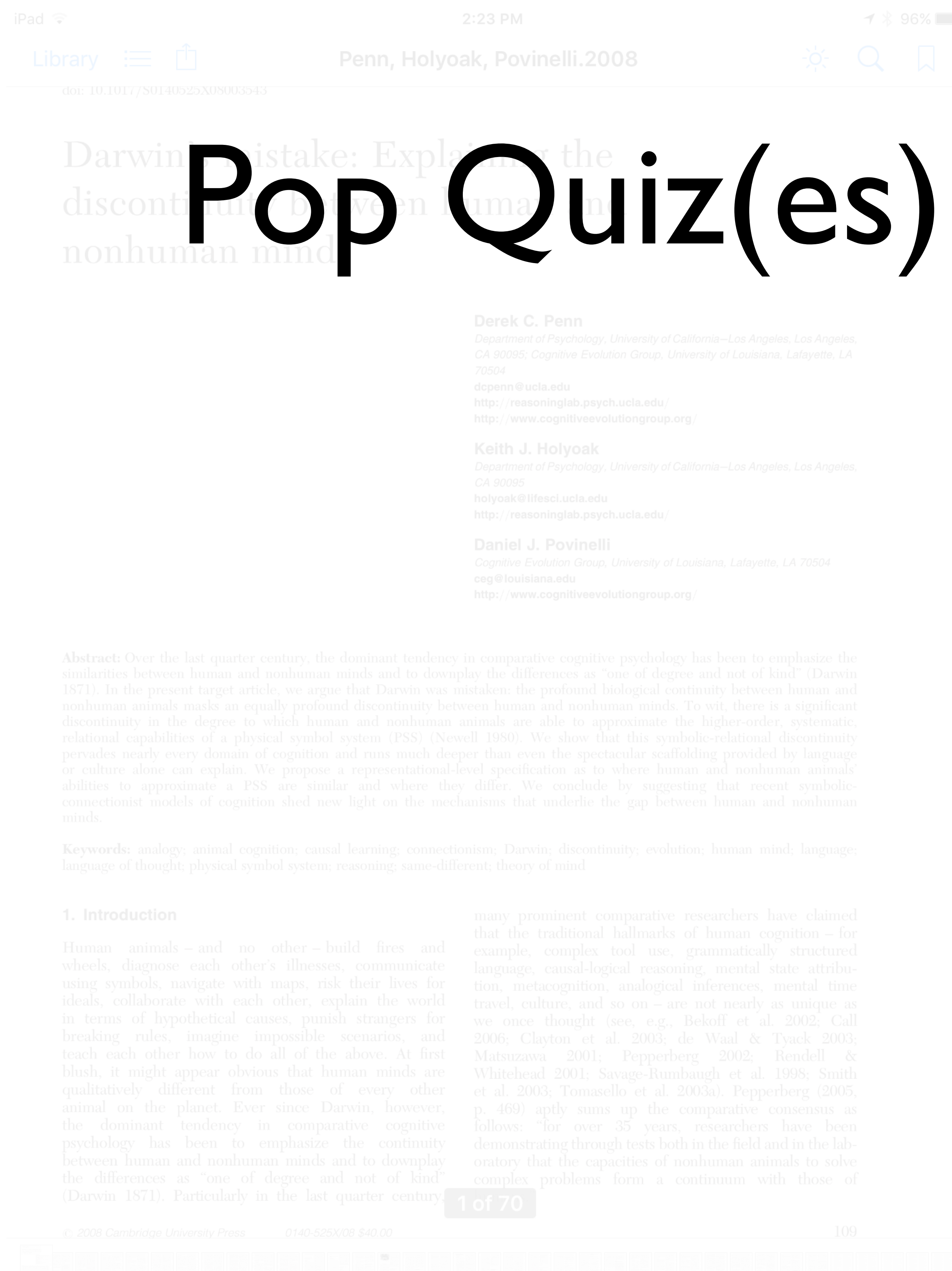
1. Introduction

Human animals – and no other – build fires and wheels, diagnose each other's illnesses, communicate using symbols, navigate with maps, risk their lives for ideals, collaborate with each other, explain the world in terms of hypothetical causes, punish strangers for breaking rules, imagine impossible scenarios, and teach each other how to do all of the above. At first blush, it might appear obvious that human minds are qualitatively different from those of every other animal on the planet. Ever since Darwin, however, the dominant tendency in comparative cognitive psychology has been to emphasize the continuity between human and nonhuman minds and to downplay the differences as "one of degree and not of kind" (Darwin 1871). Particularly in the last quarter century, many prominent comparative researchers have claimed that the traditional hallmarks of human cognition – for example, complex tool use, grammatically structured language, causal-logical reasoning, mental state attribution, metacognition, analogical inferences, mental time travel, culture, and so on – are not nearly as unique as we once thought (see, e.g., Bekoff et al. 2002; Call 2006; Clayton et al. 2003; de Waal & Tyack 2003; Matsuzawa 2001; Pepperberg 2002; Rendell & Whitehead 2001; Savage-Rumbaugh et al. 1998; Smith et al. 2003; Tomasello et al. 2003a). Pepperberg (2005, p. 469) aptly sums up the comparative consensus as follows: "for over 35 years, researchers have been demonstrating through tests both in the field and in the laboratory that the capacities of nonhuman animals to solve complex problems form a continuum with those of

1 of 70

 0140-525X/08 $40.00

The Paper

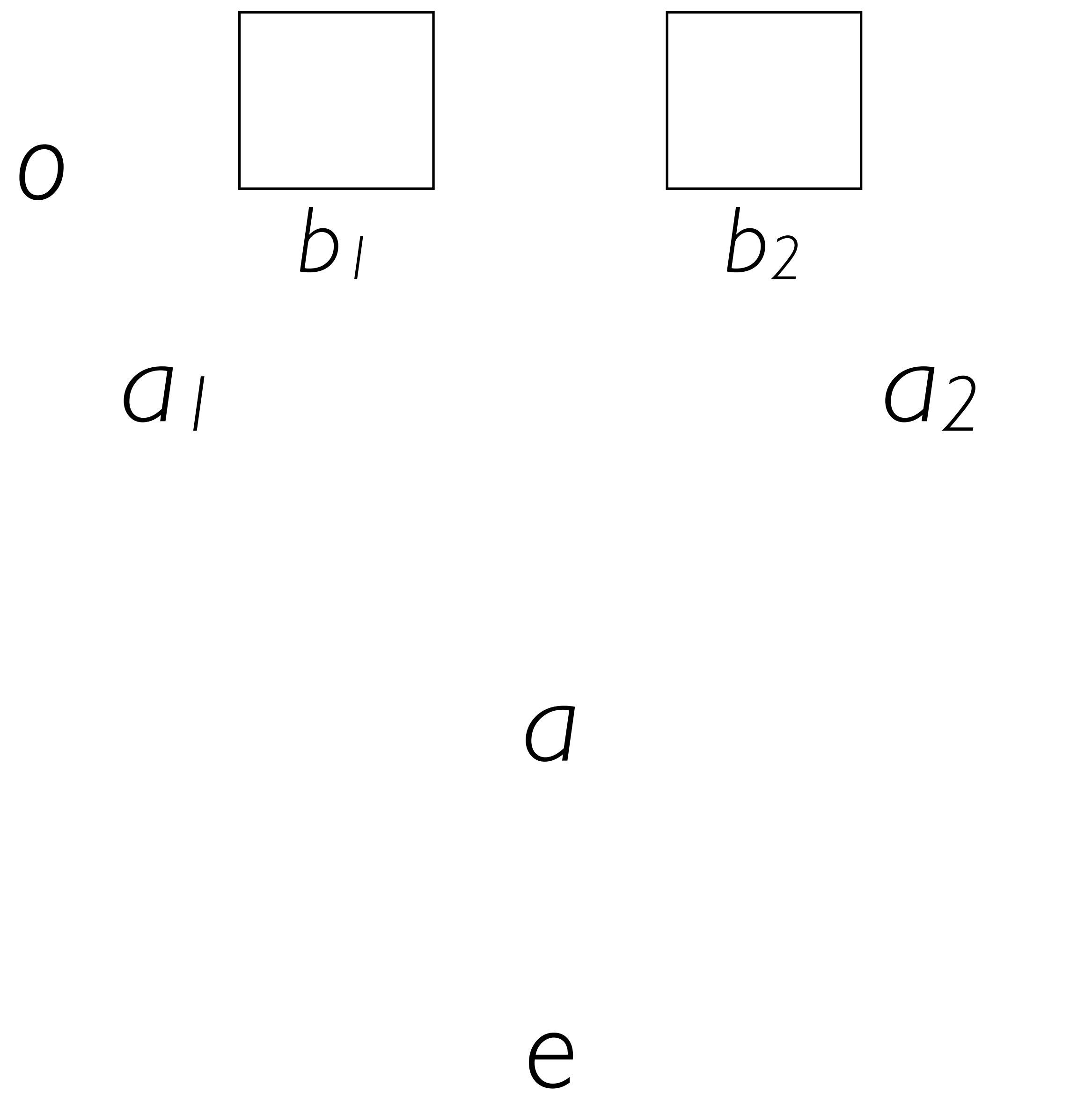


Pop Quiz(es)

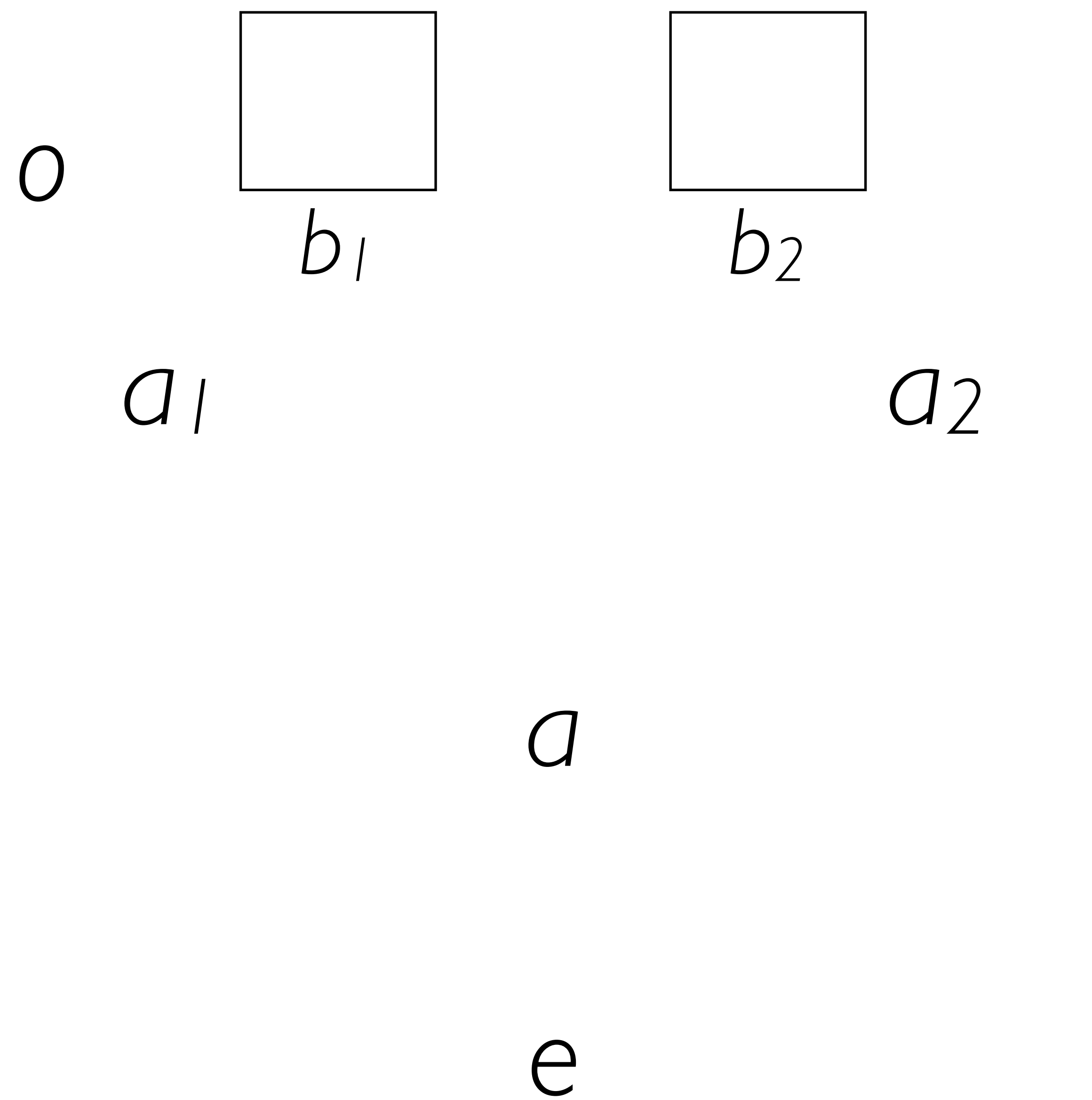
Pop Quiz(es)

Can nonhuman animals solve FB_1^2?

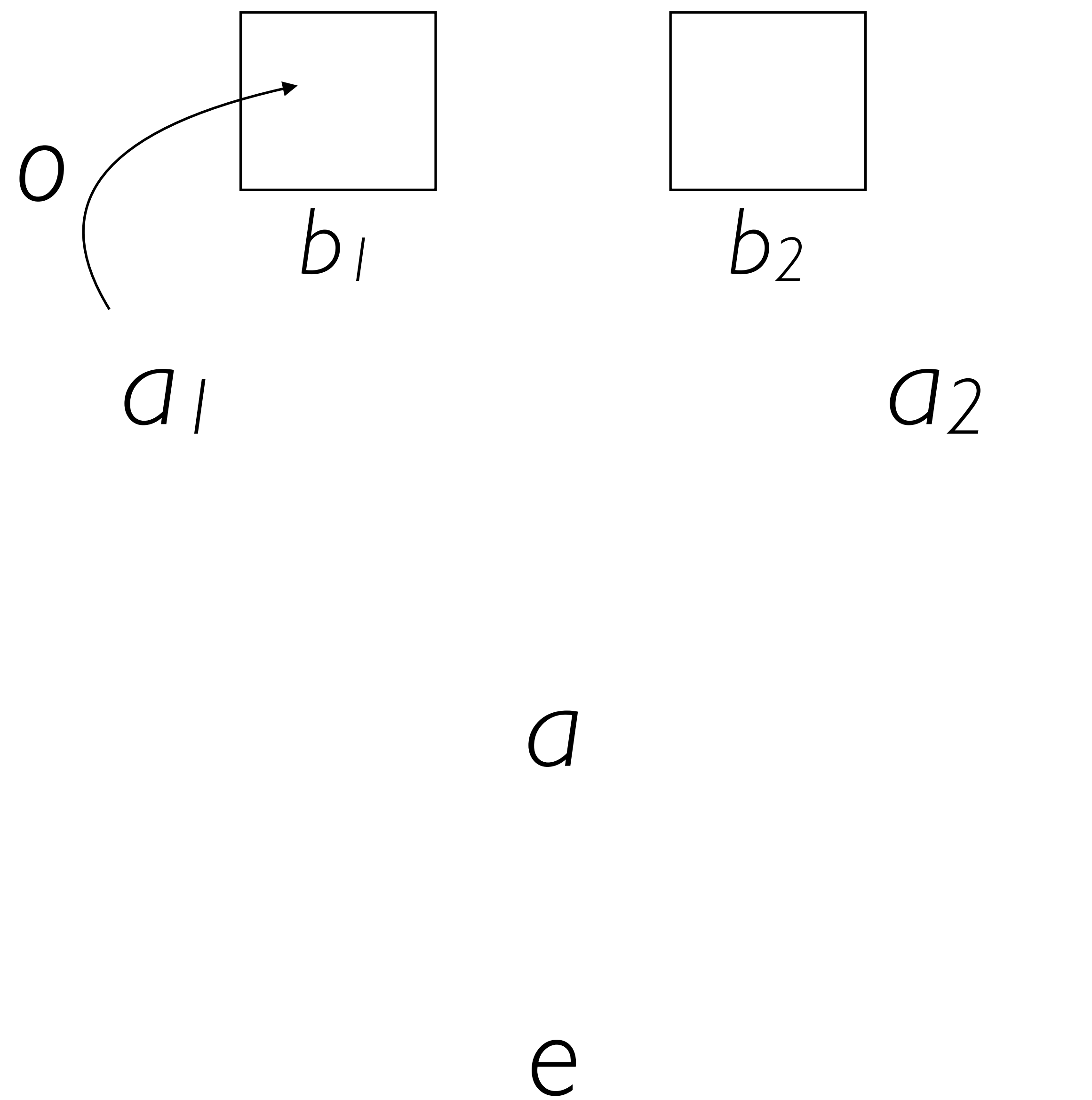
Framework for FBT^0_1



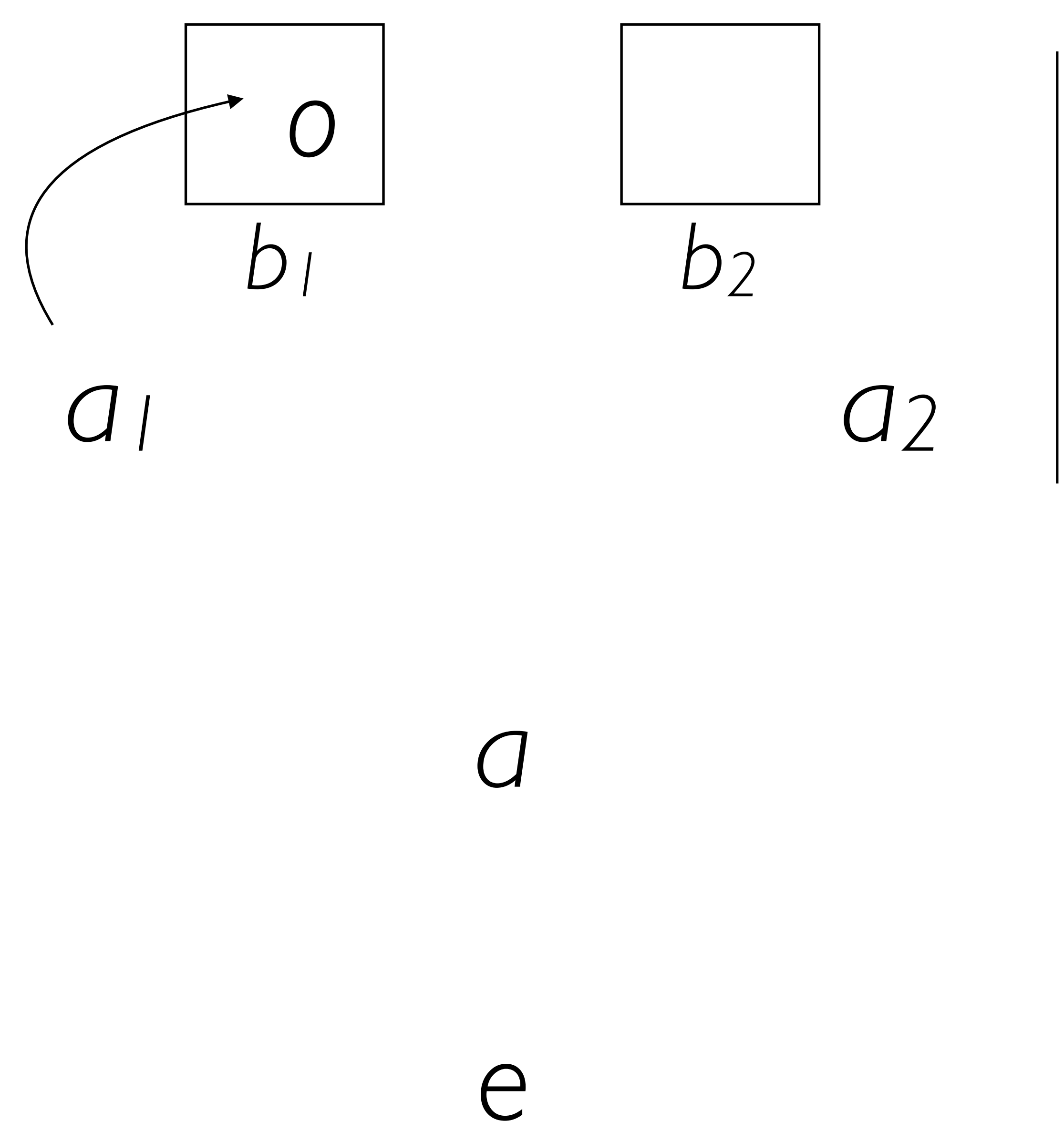
Framework for FBT^0_1
(five timepoints)



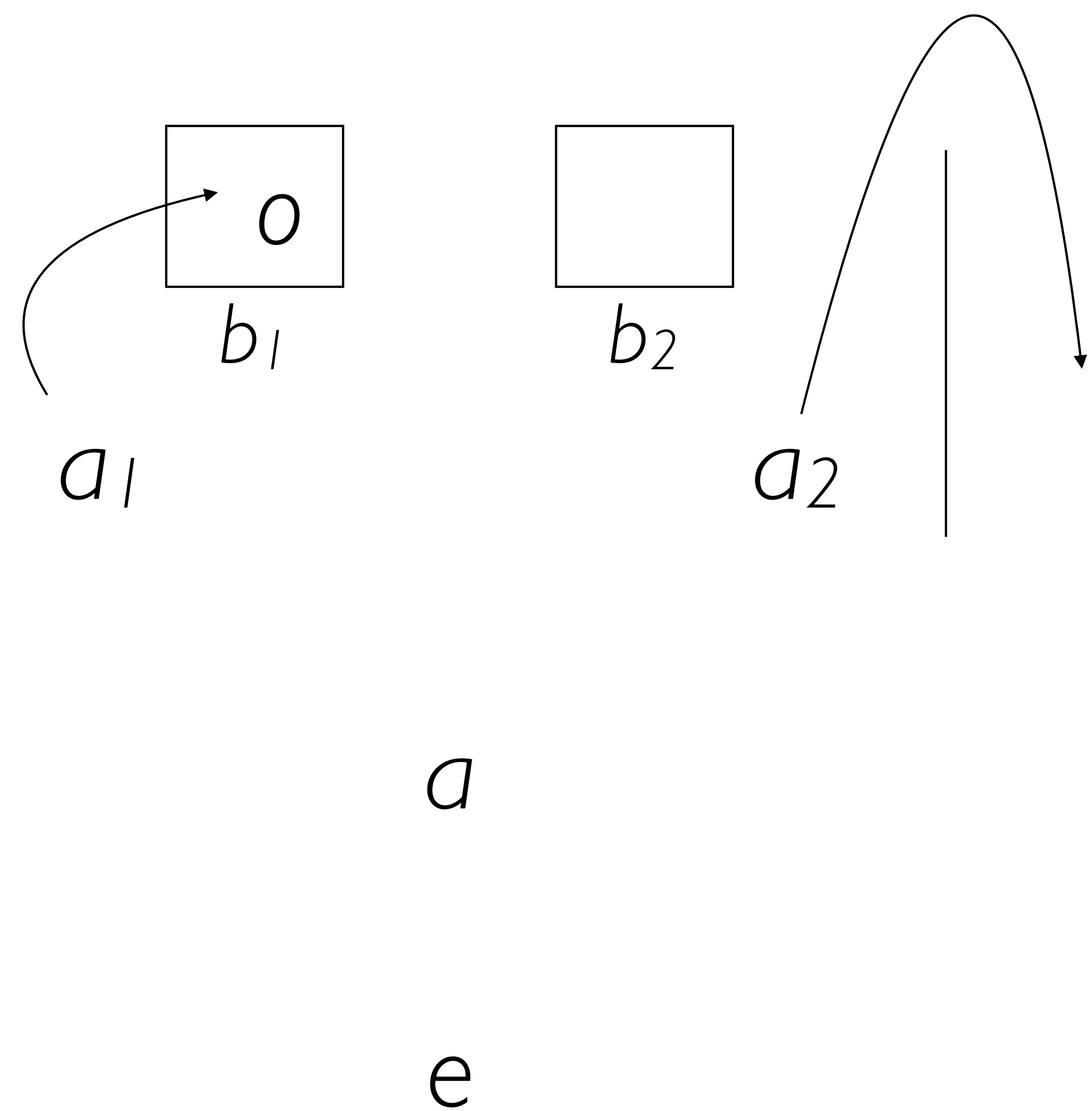
Framework for $FBT^0{}_1$
(five timepoints)



Framework for $FBT^0{}_1$
(five timepoints)

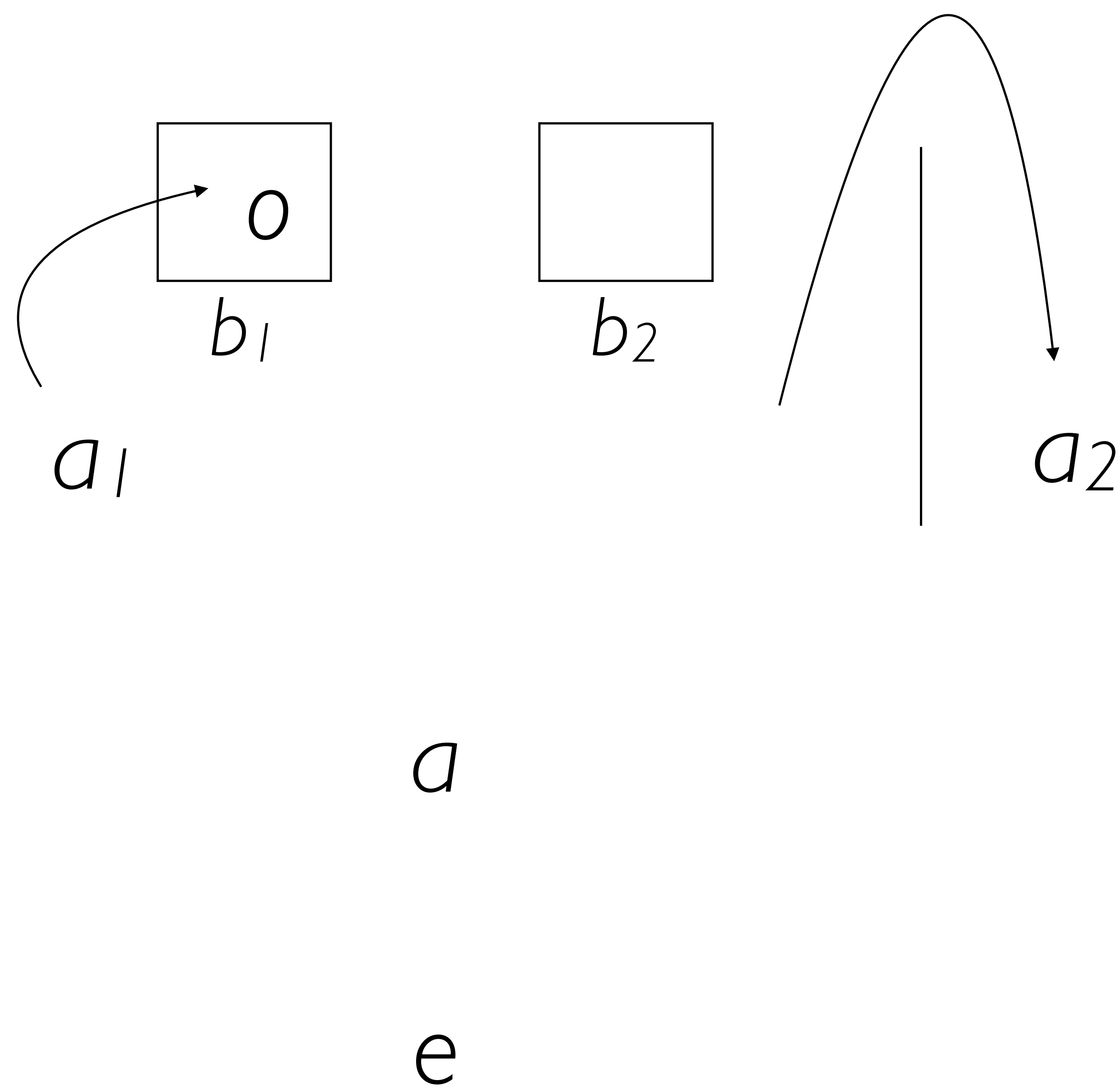


Framework for FBT^0_1
(five timepoints)

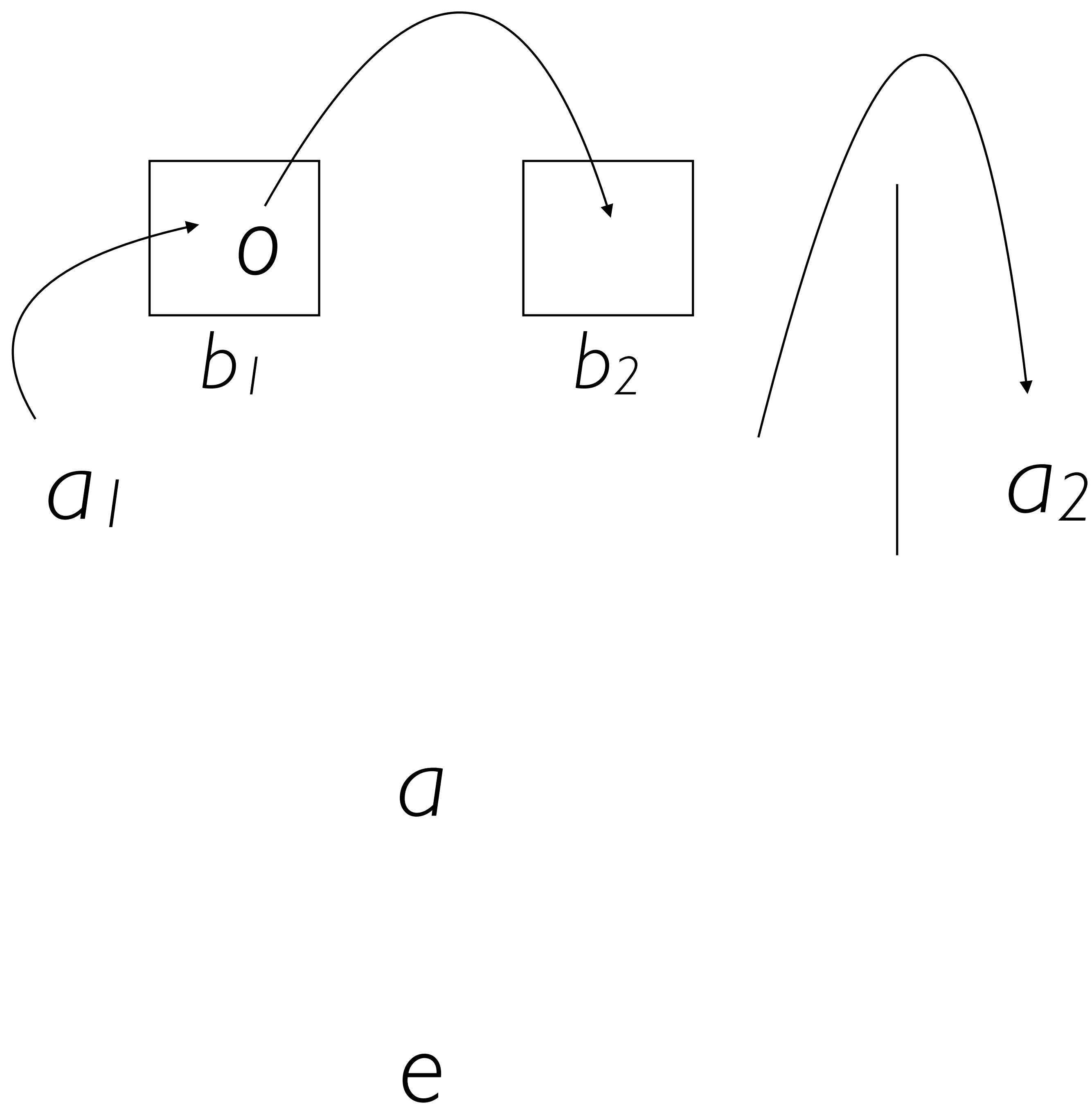


Framework for FBT^0_1

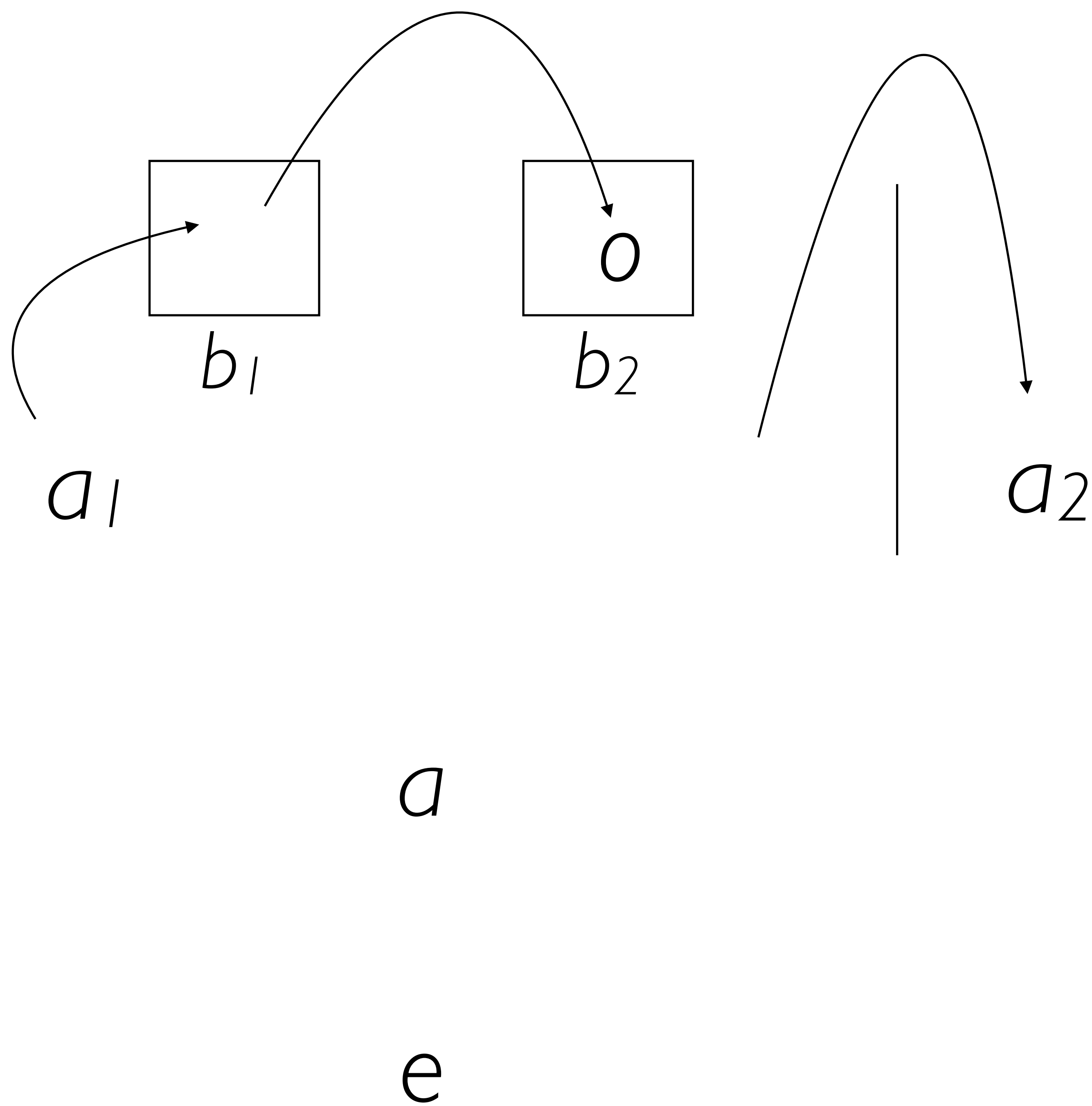
(five timepoints)



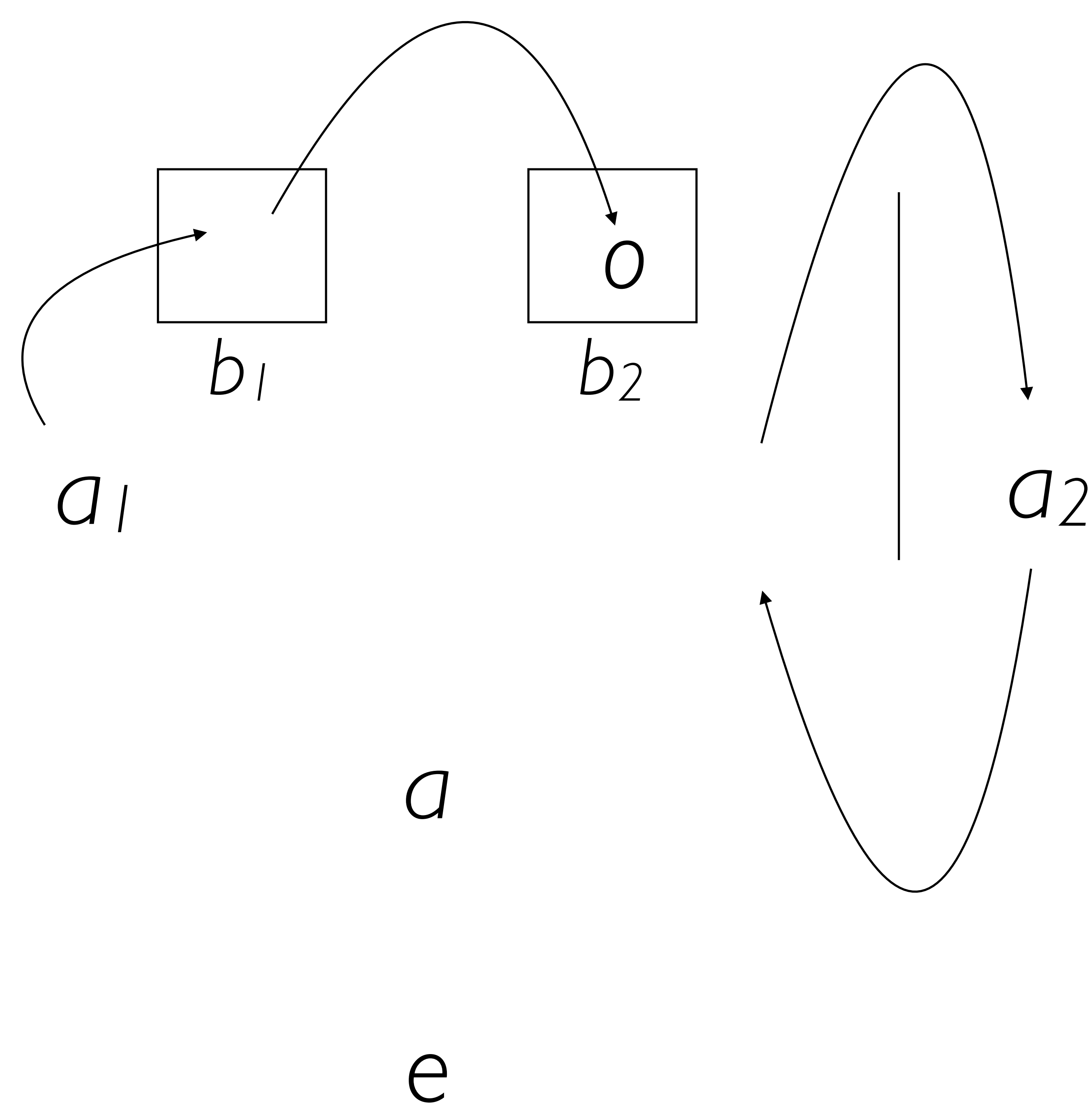
Framework for $FBT^0{}_1$
(five timepoints)



Framework for $FBT^0{}_1$
(five timepoints)

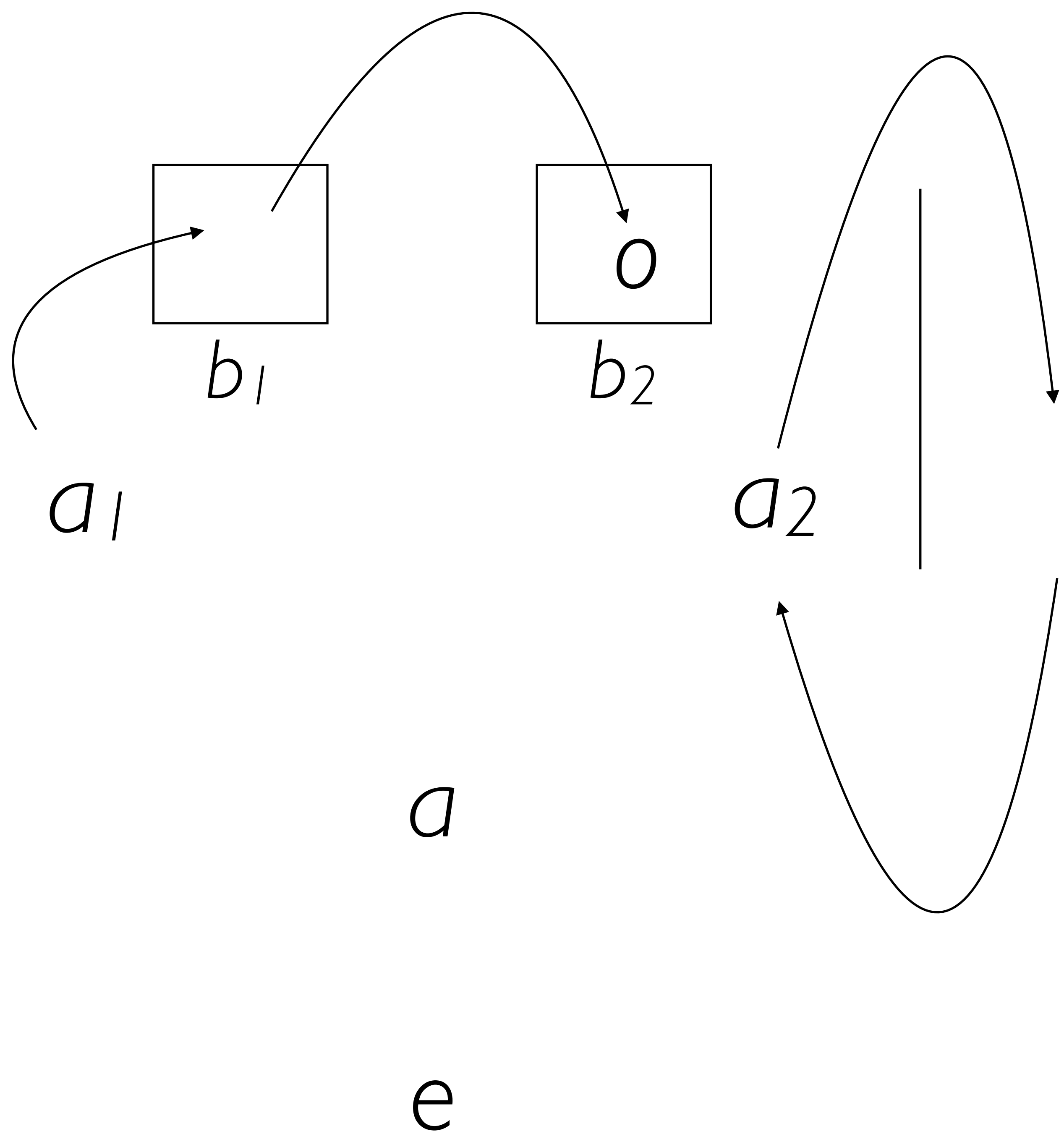


Framework for FBT$^0{}_1$
(five timepoints)

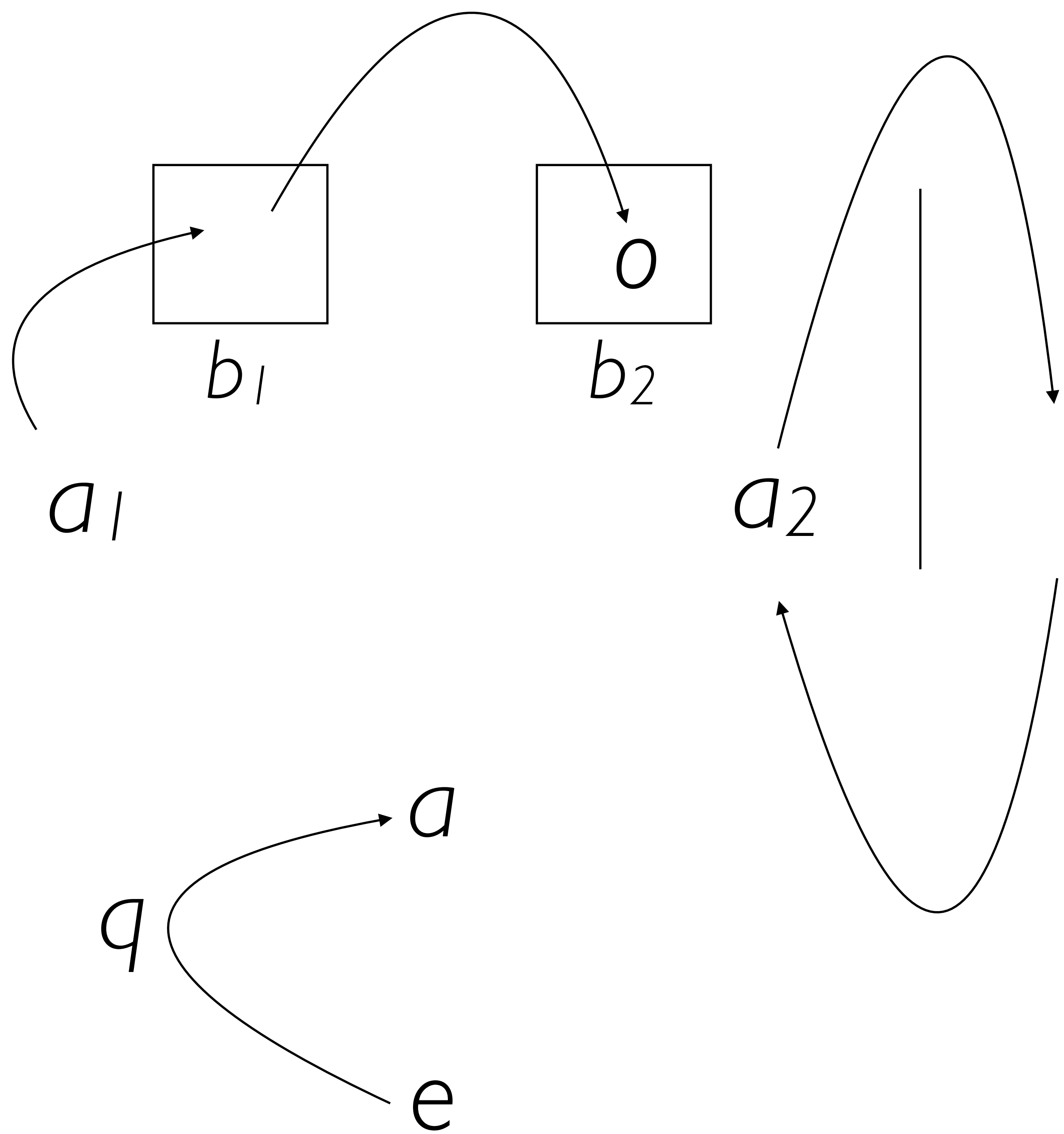


Framework for $FBT^0{}_1$

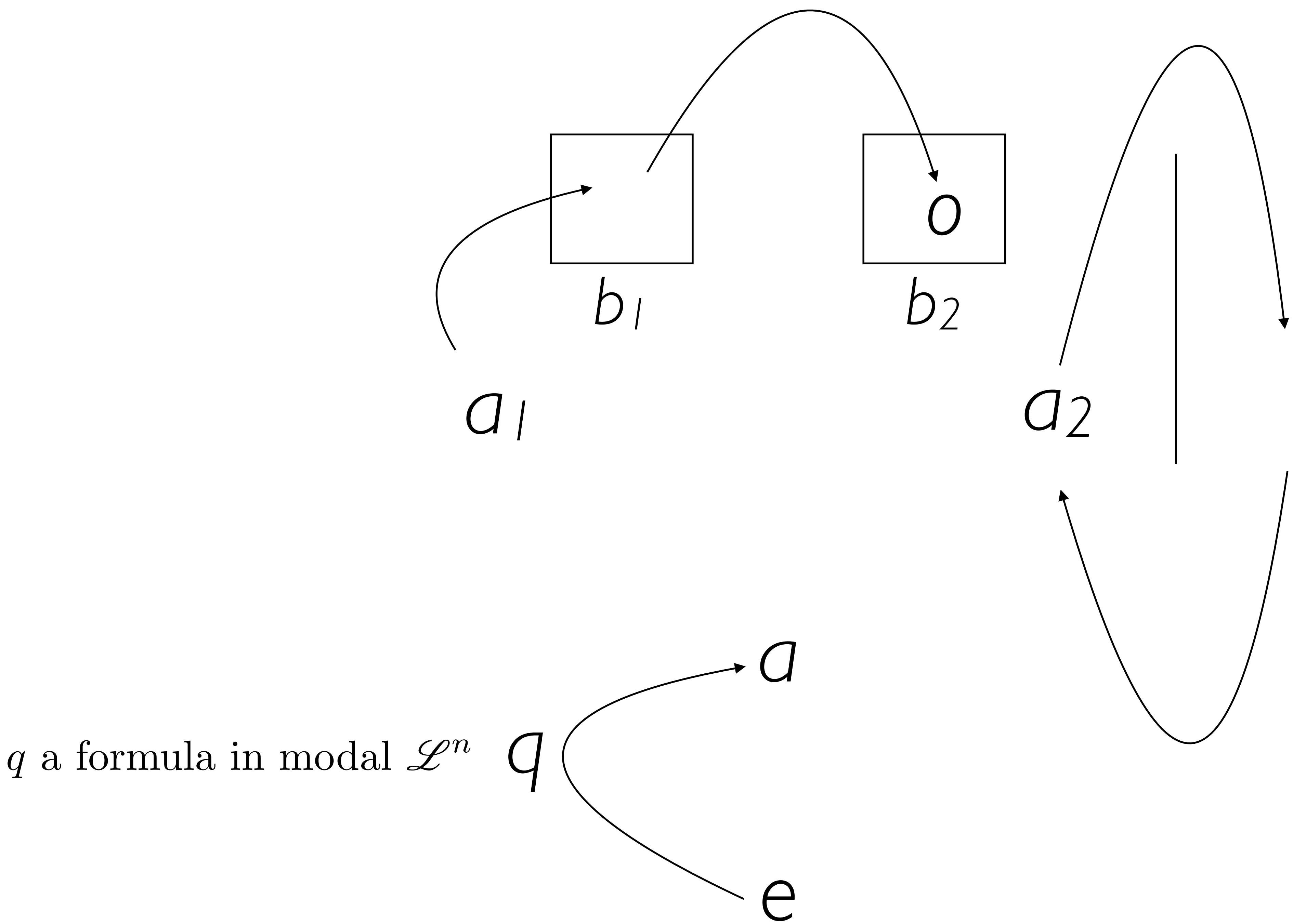
(five timepoints)



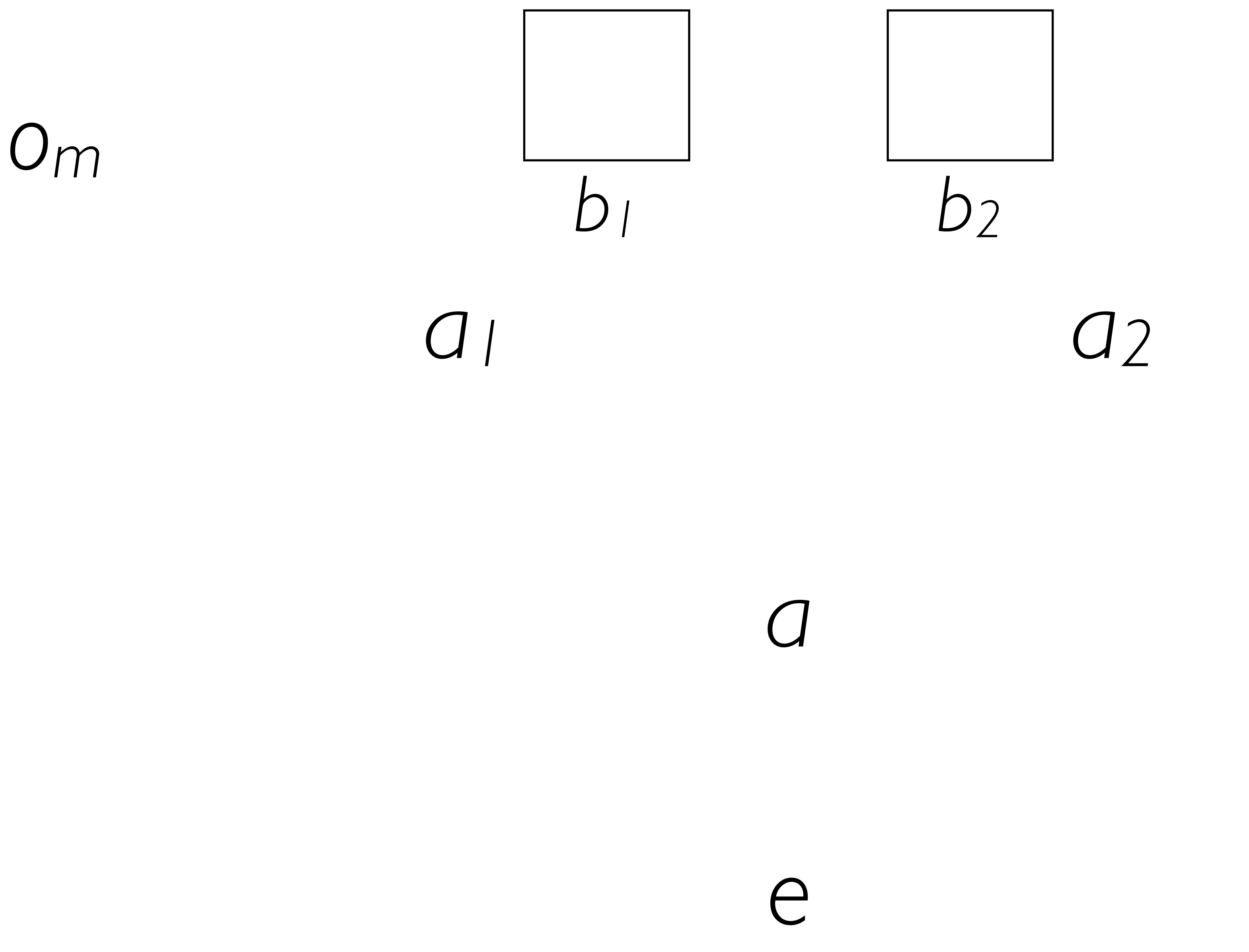
Framework for $FBT^0{}_1$
(five timepoints)



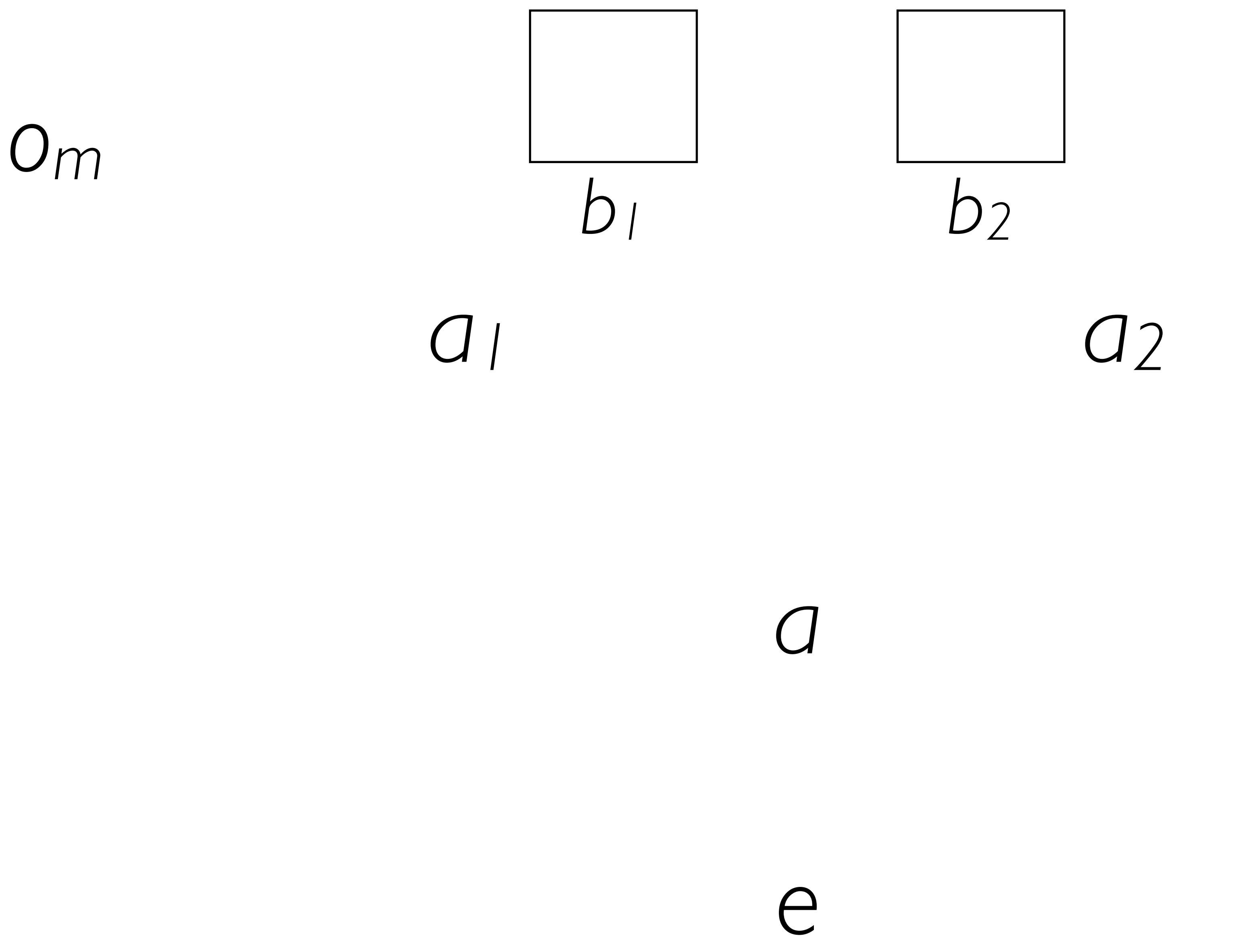
Framework for $FBT^0{}_1$
(five timepoints)



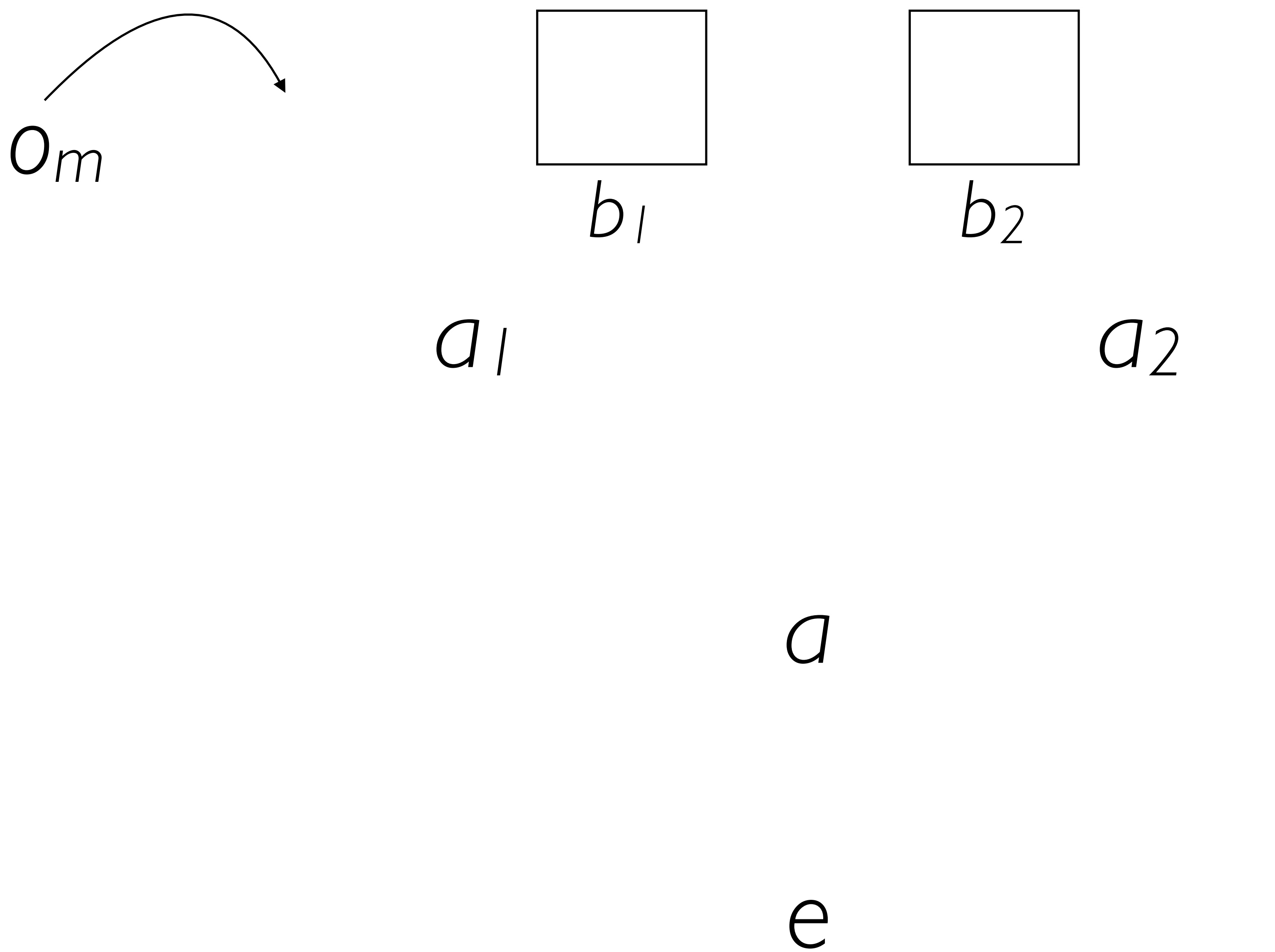
Framework for FBT^1_1



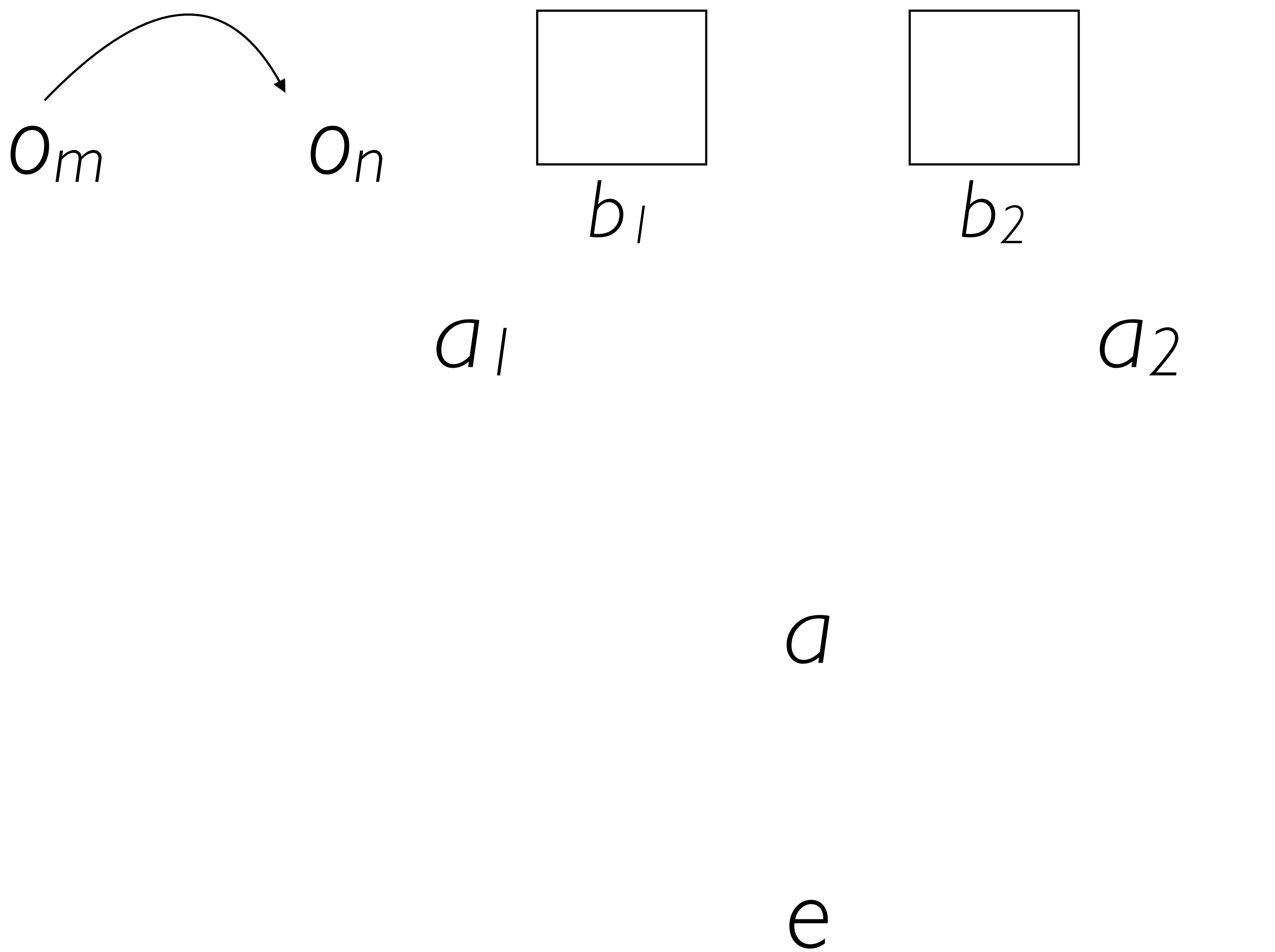
Framework for FBT^1_1
(six timepoints)



Framework for FBT$^1_1$
(six timepoints)

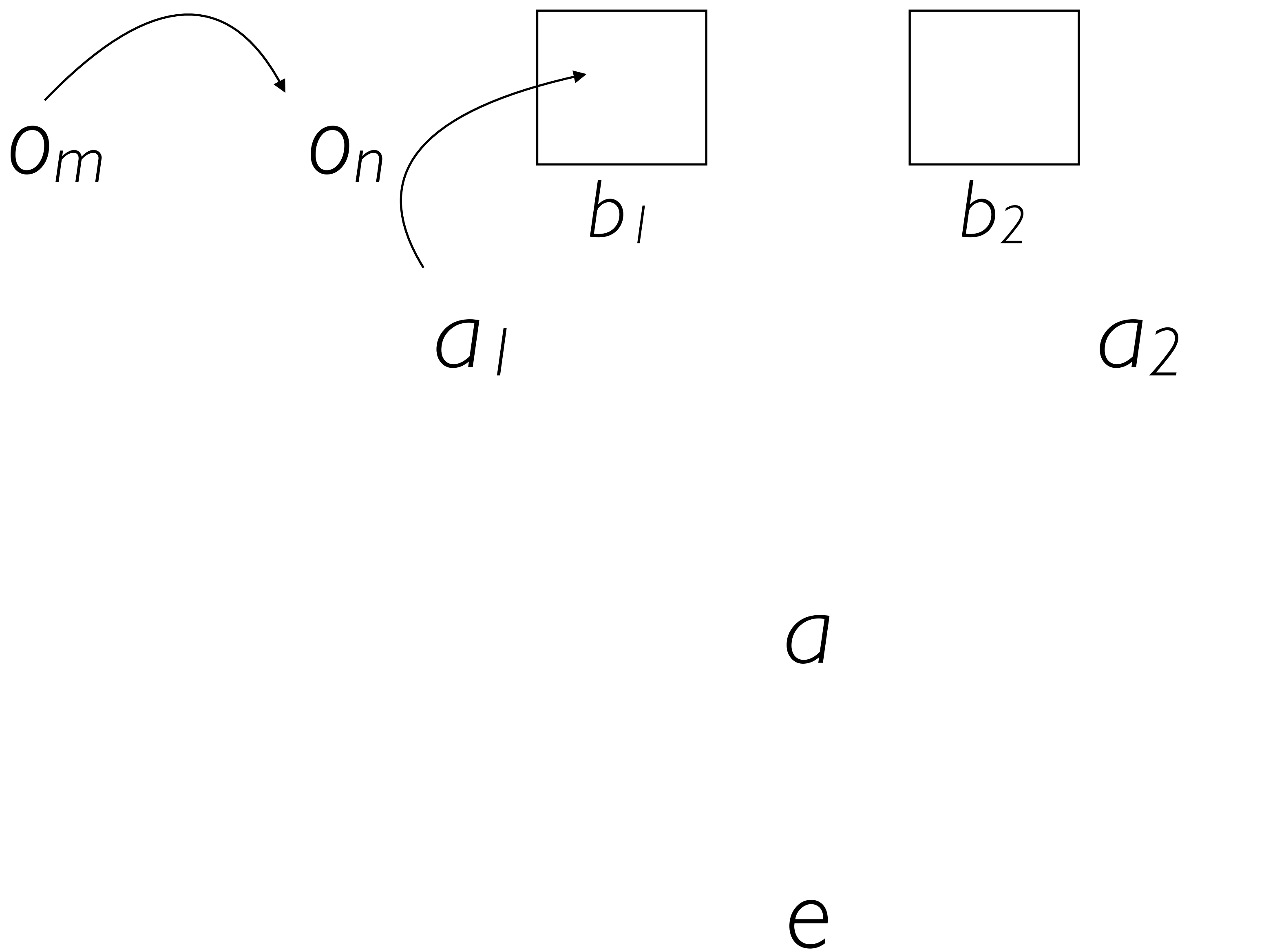


Framework for $FBT^1{}_1$
(six timepoints)



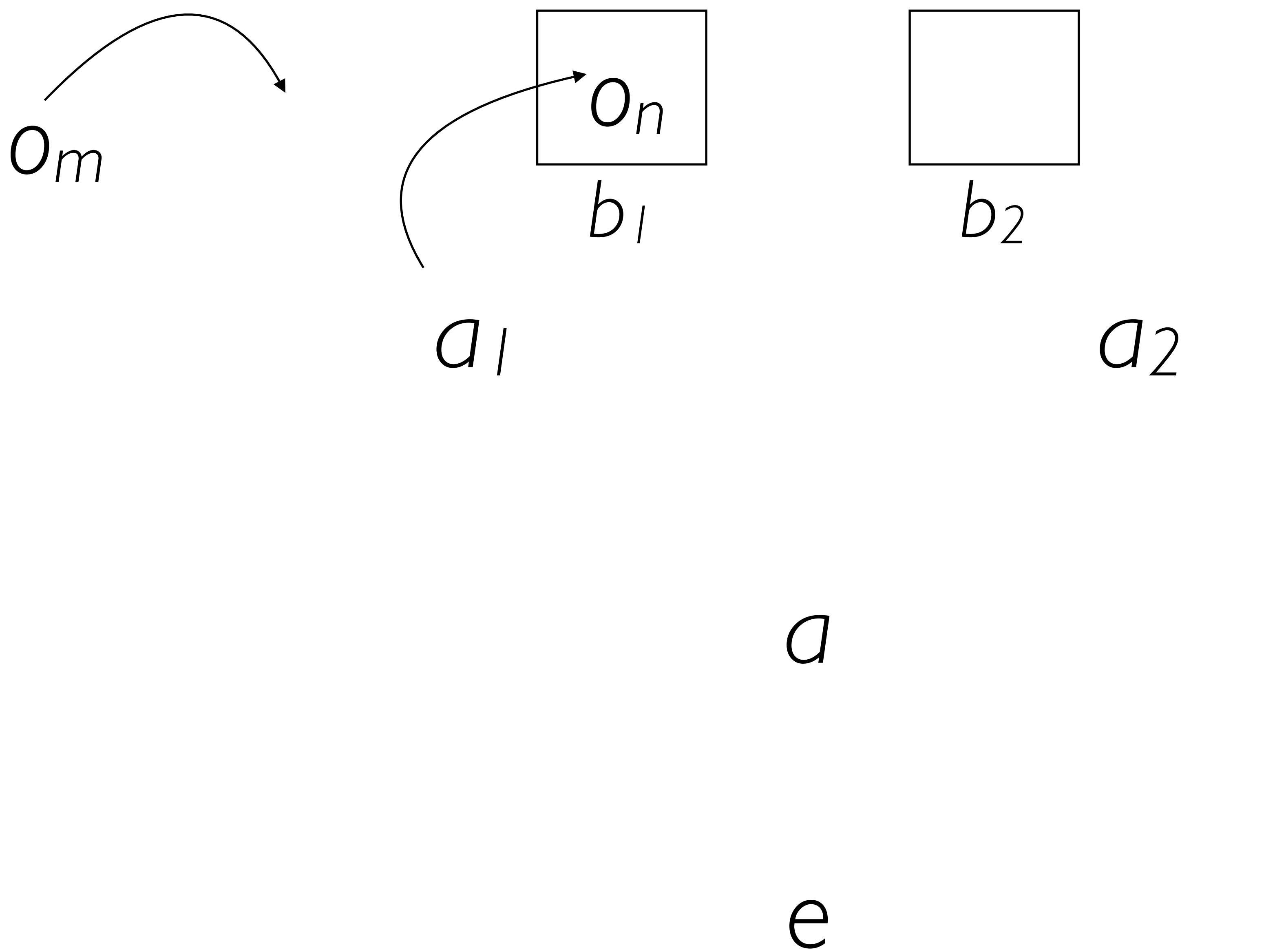
Framework for $FBT^1{}_1$

(six timepoints)

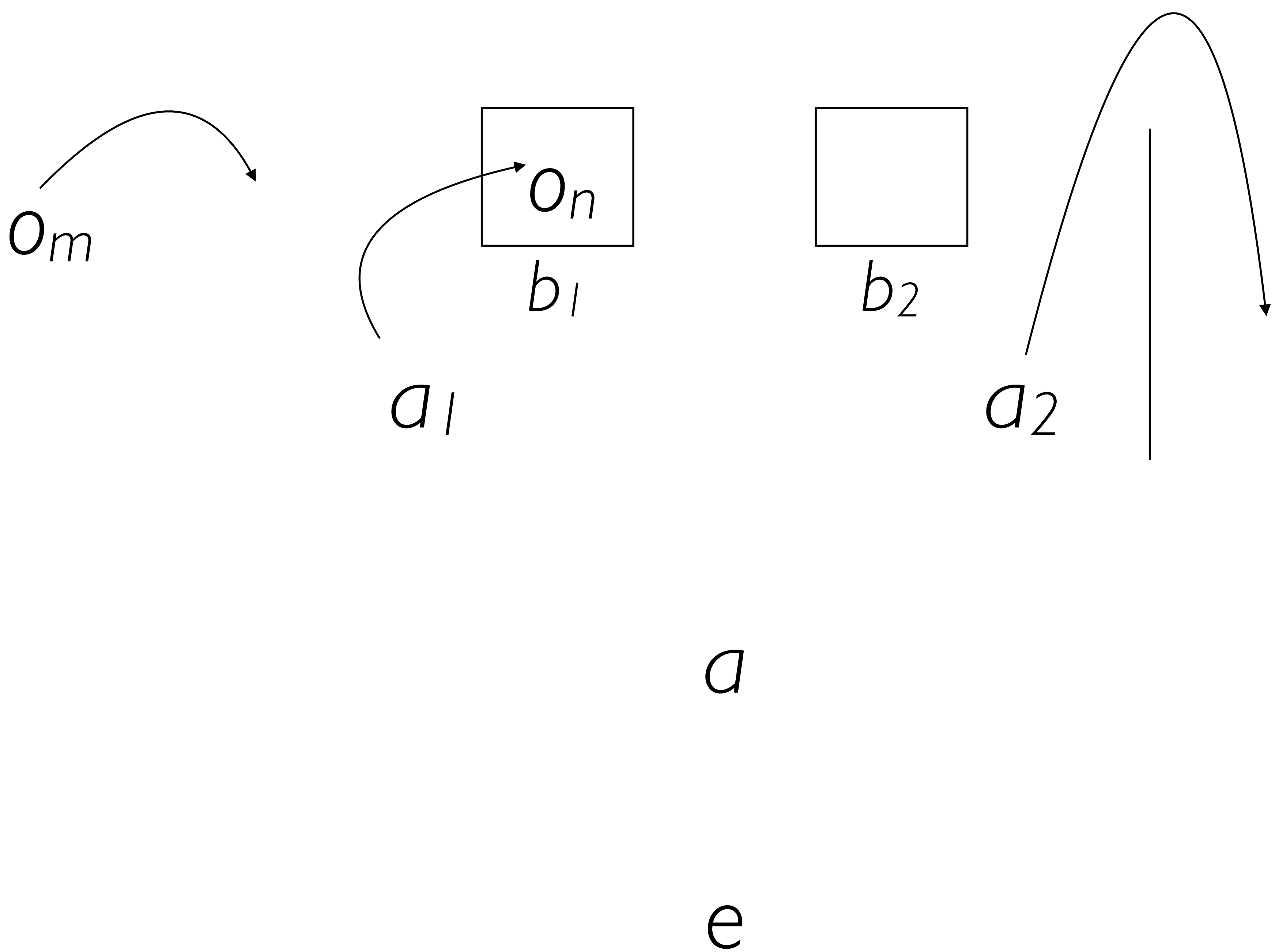


Framework for FBT'$_1$

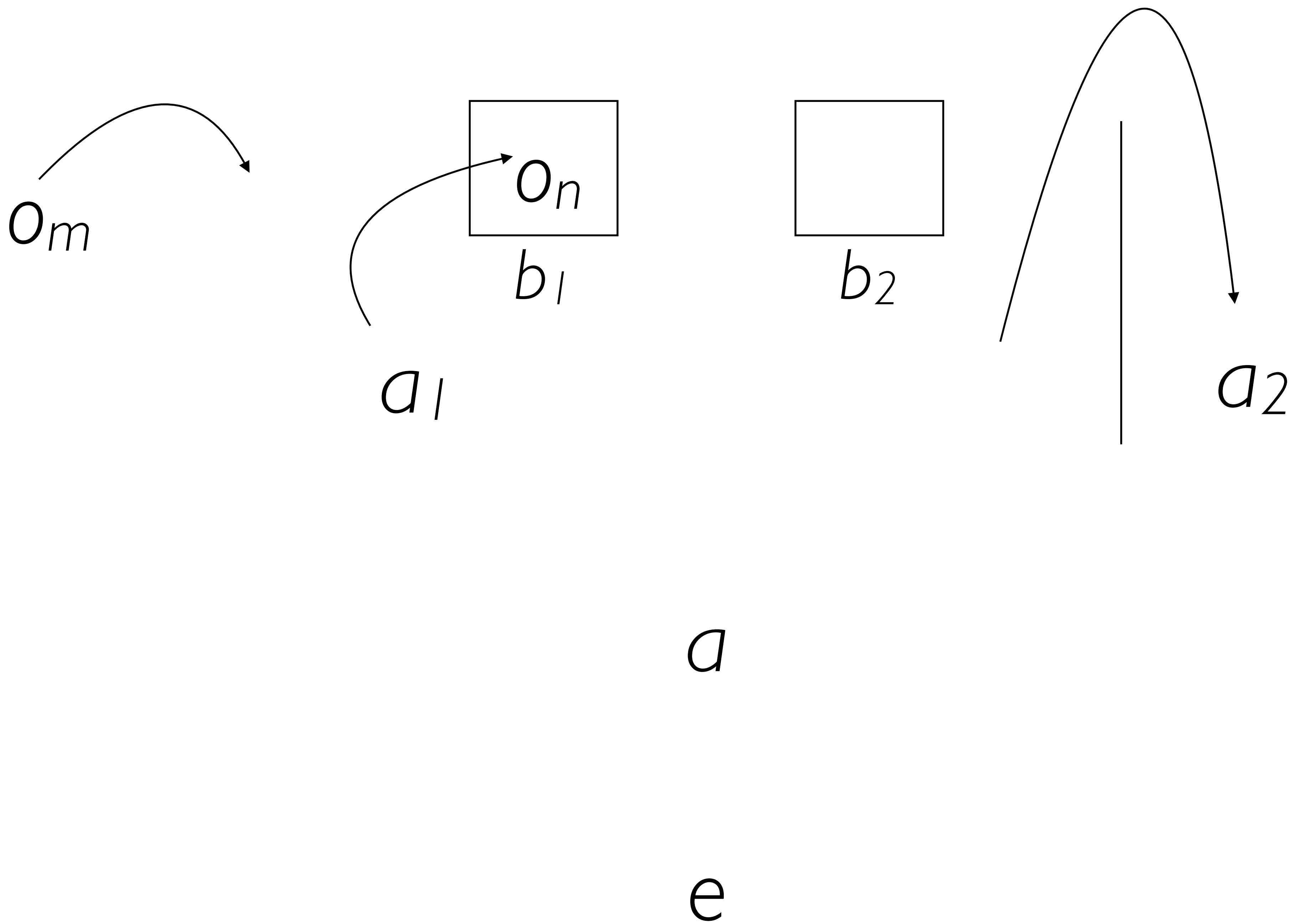
(six timepoints)



Framework for FBT^{1}_{1}
(six timepoints)

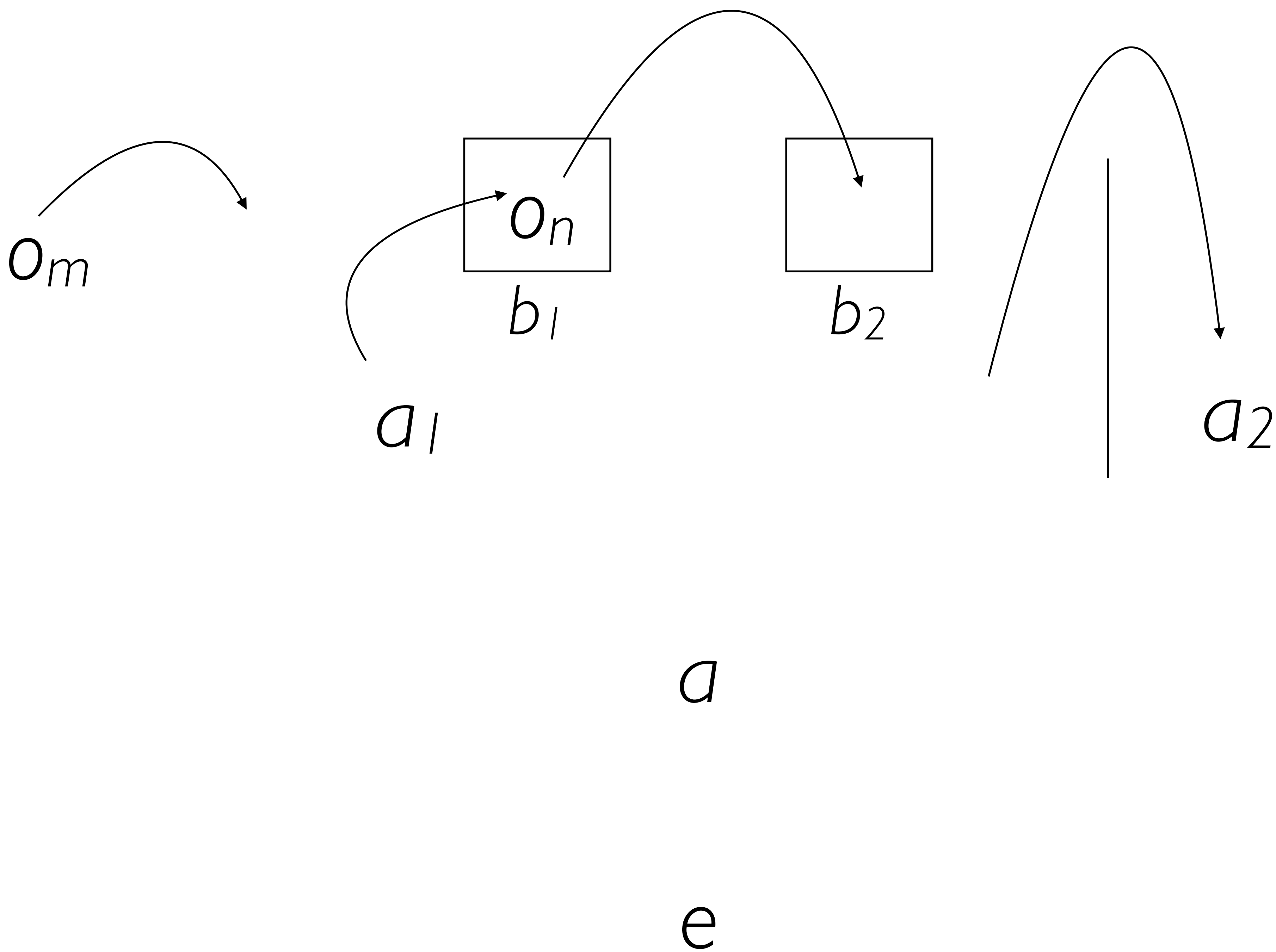


Framework for FBT$^1_1$
(six timepoints)

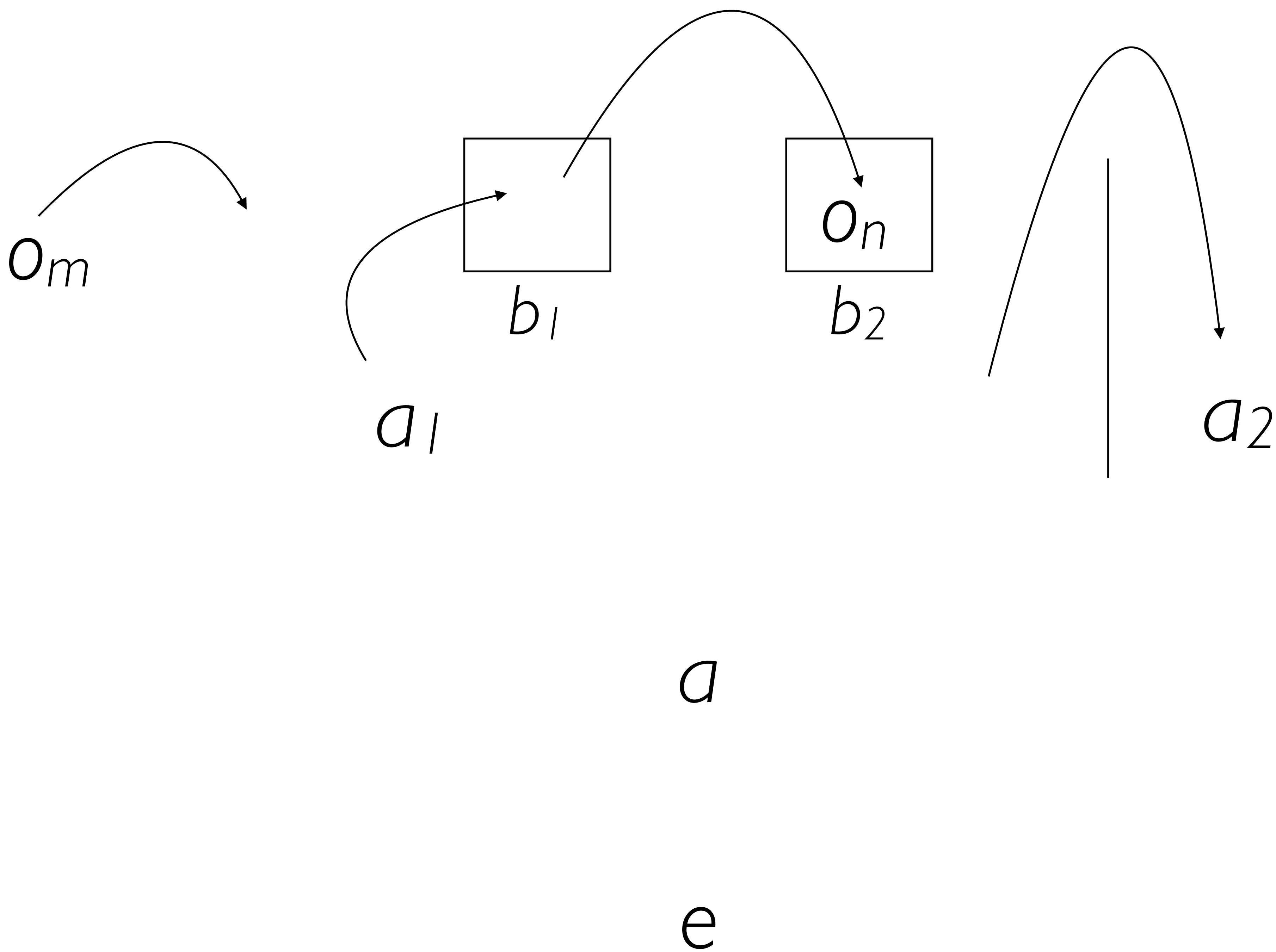


Framework for $FBT^1{}_1$

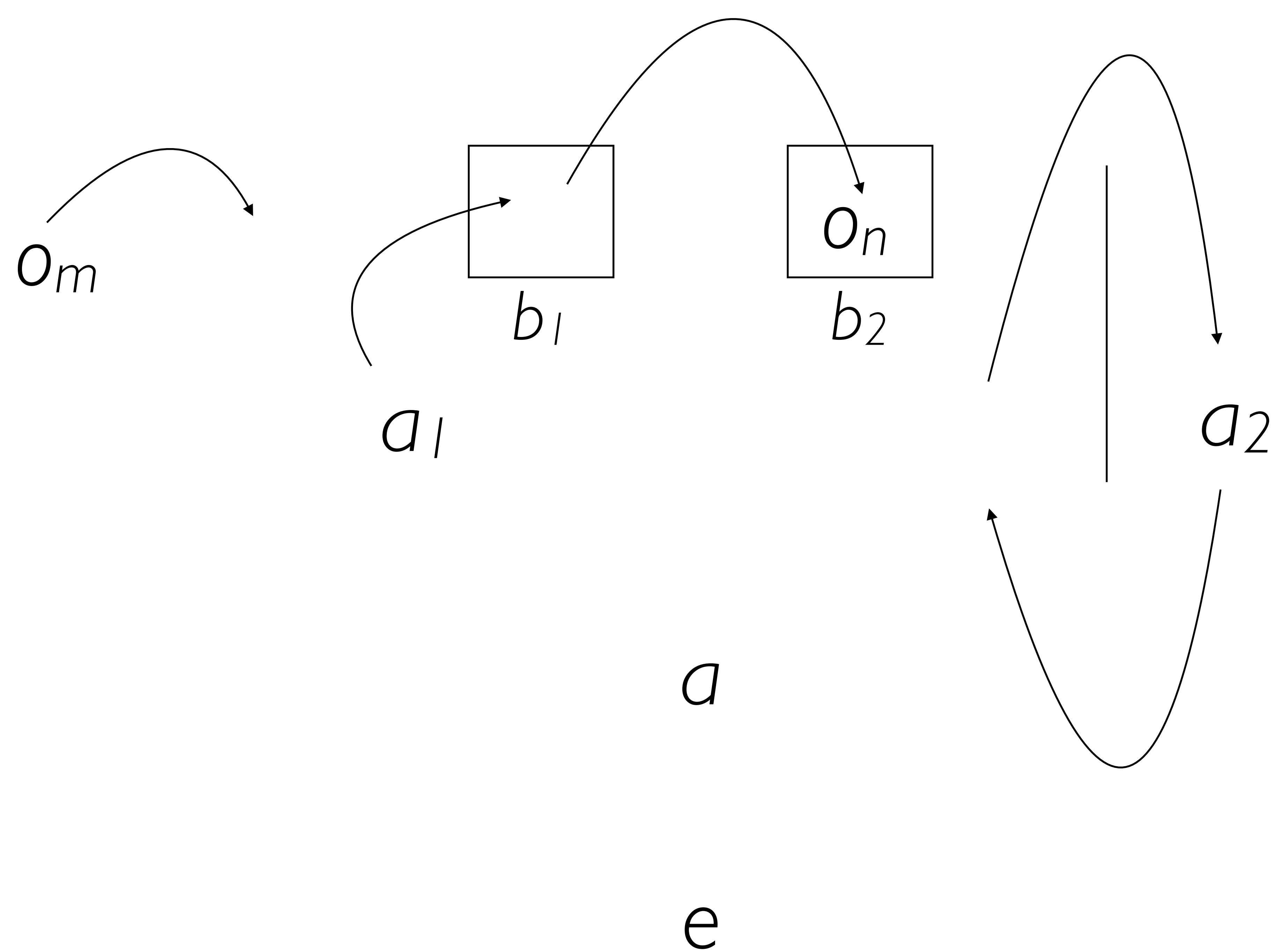
(six timepoints)



Framework for $FBT^1{}_1$
(six timepoints)

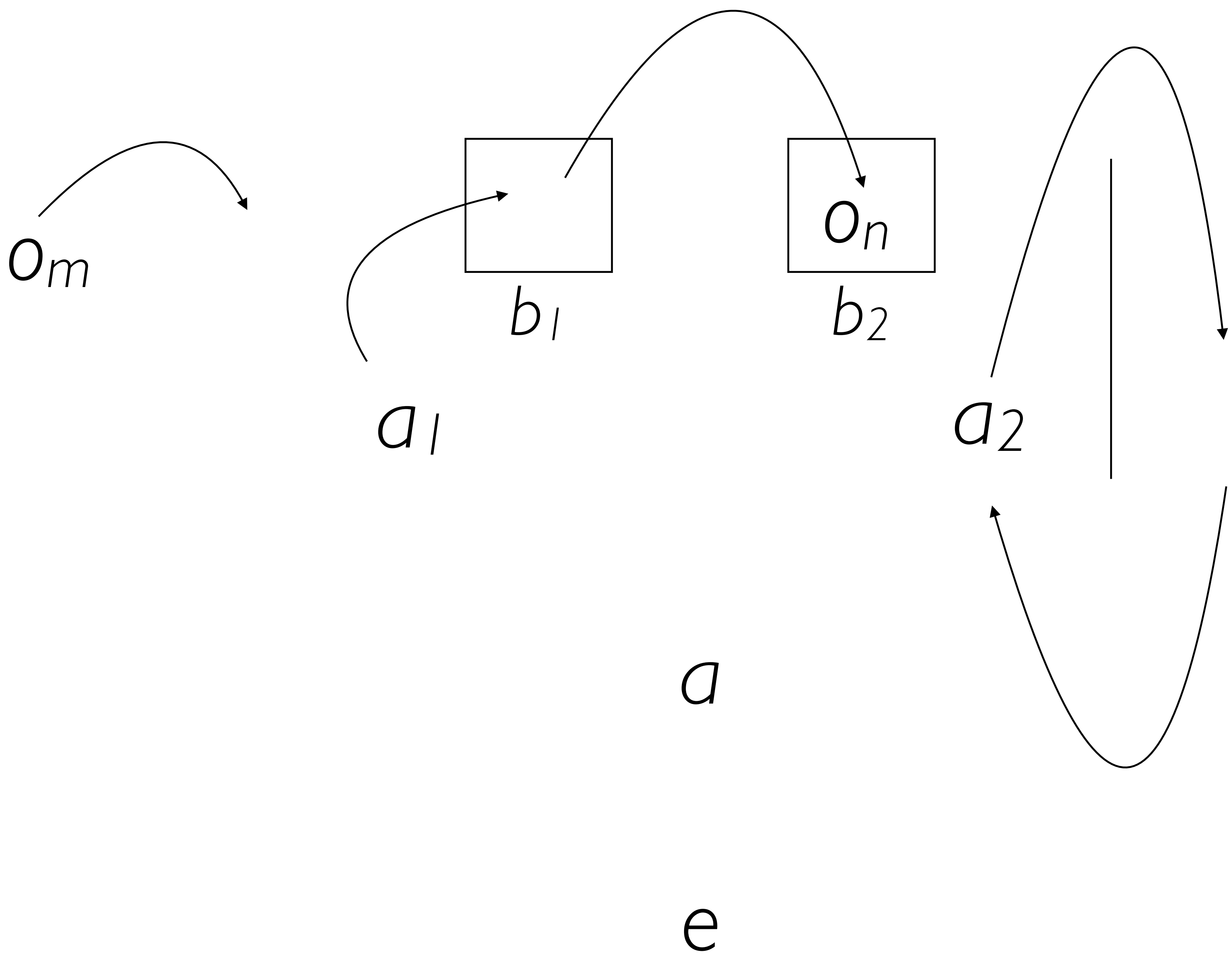


Framework for $FBT^1{}_1$
(six timepoints)

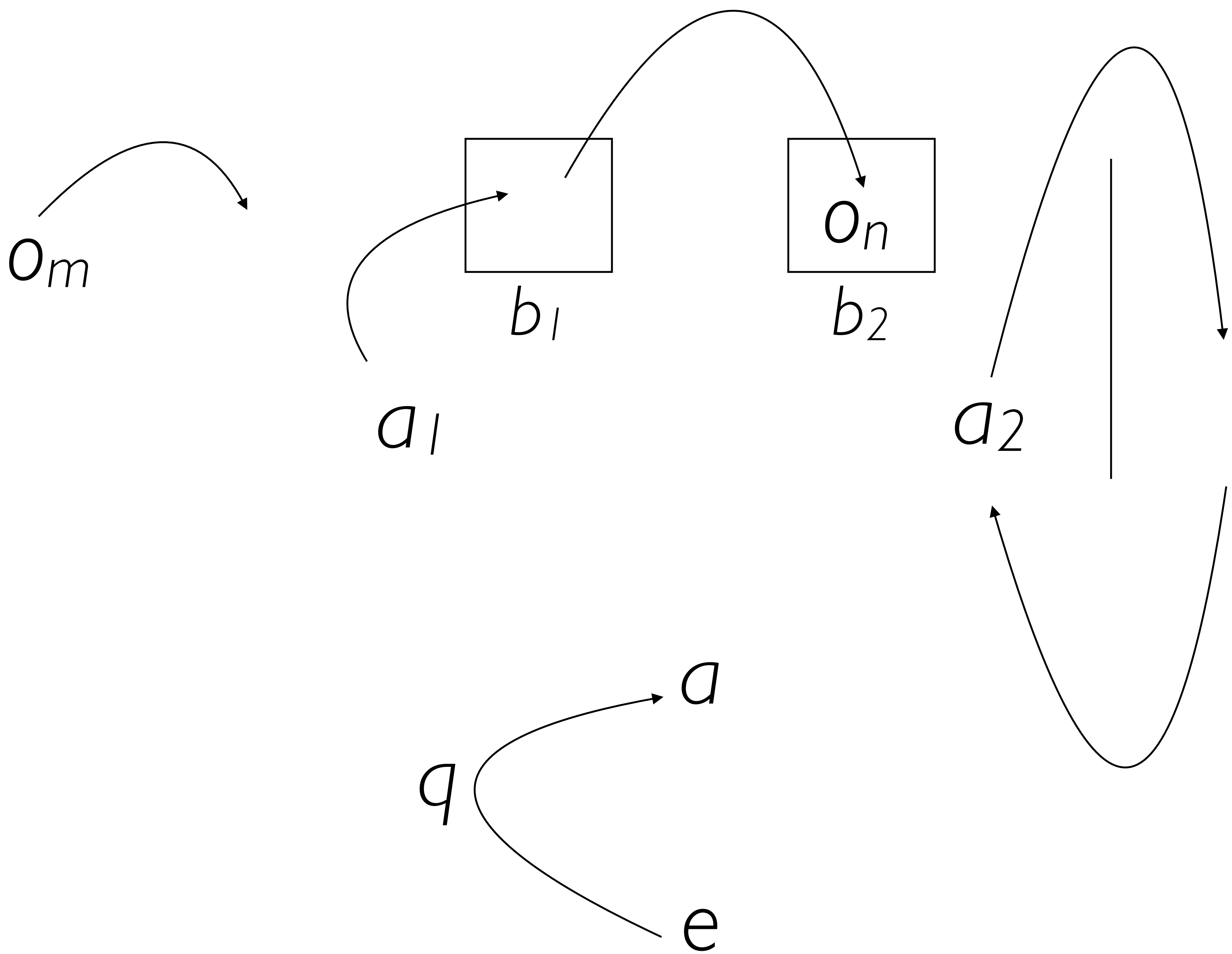


Framework for FBT$^1{}_1$

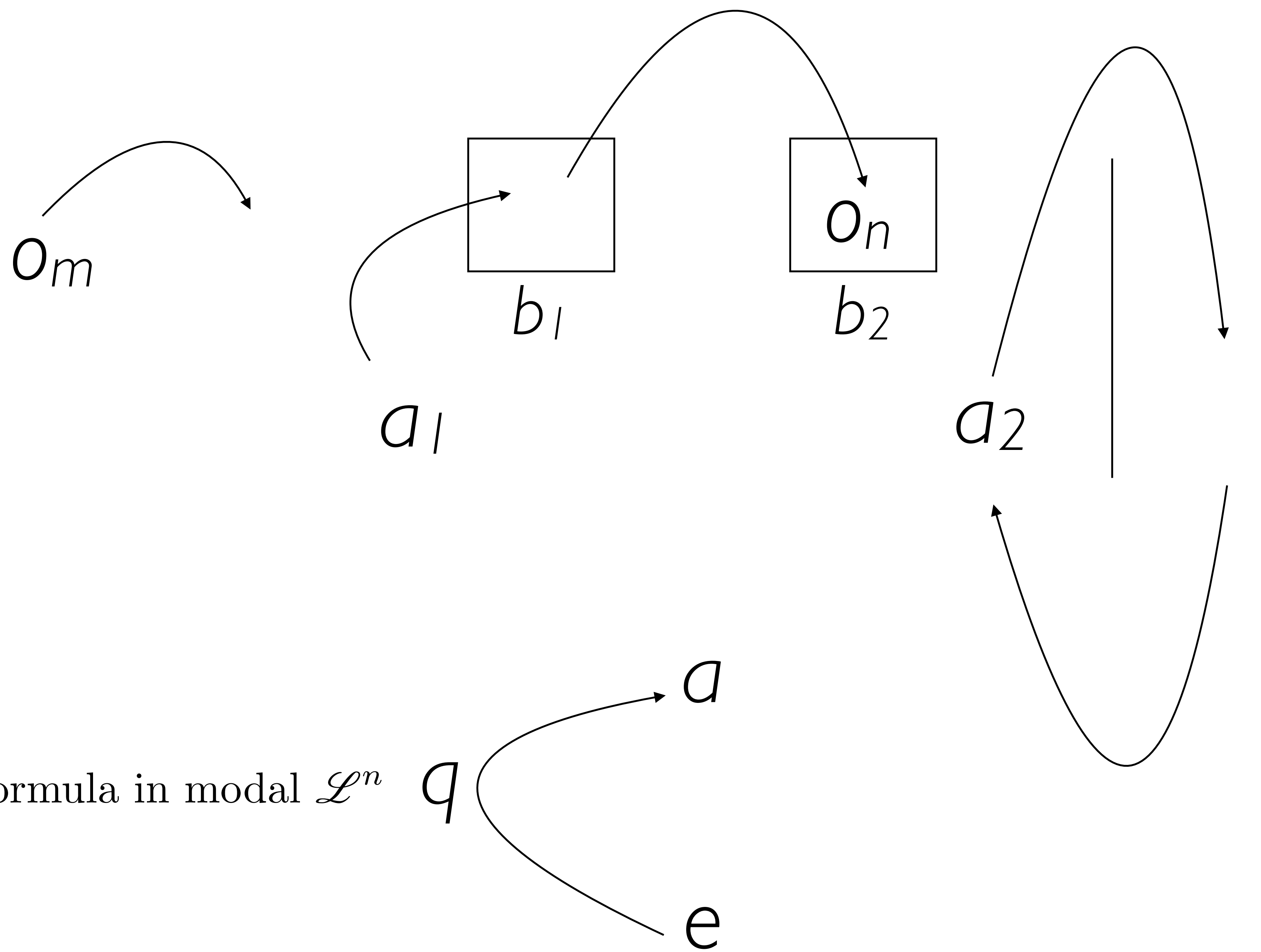
(six timepoints)



Framework for FBT1$_1$
(six timepoints)

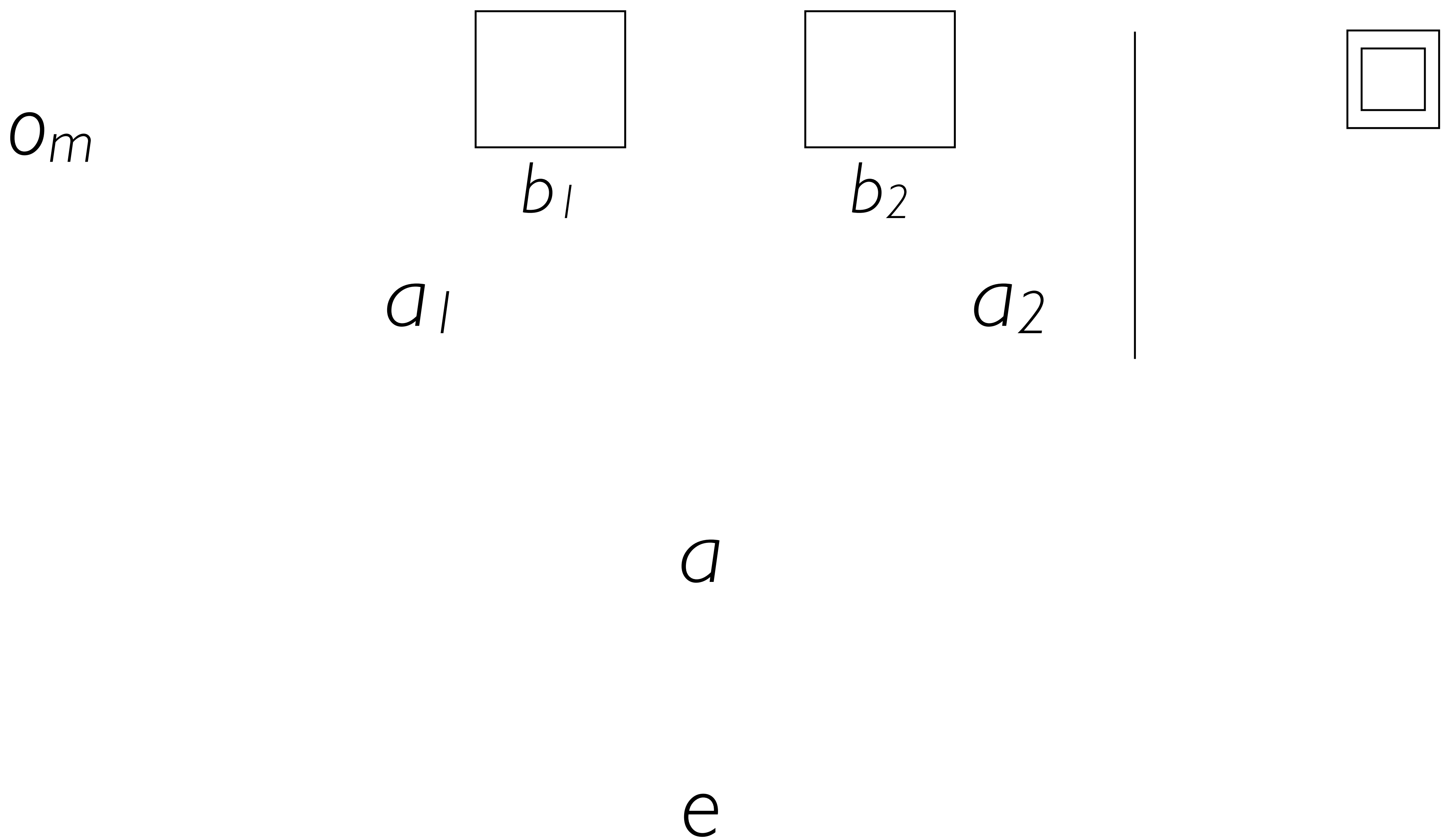


Framework for FBT^1_1
(six timepoints)

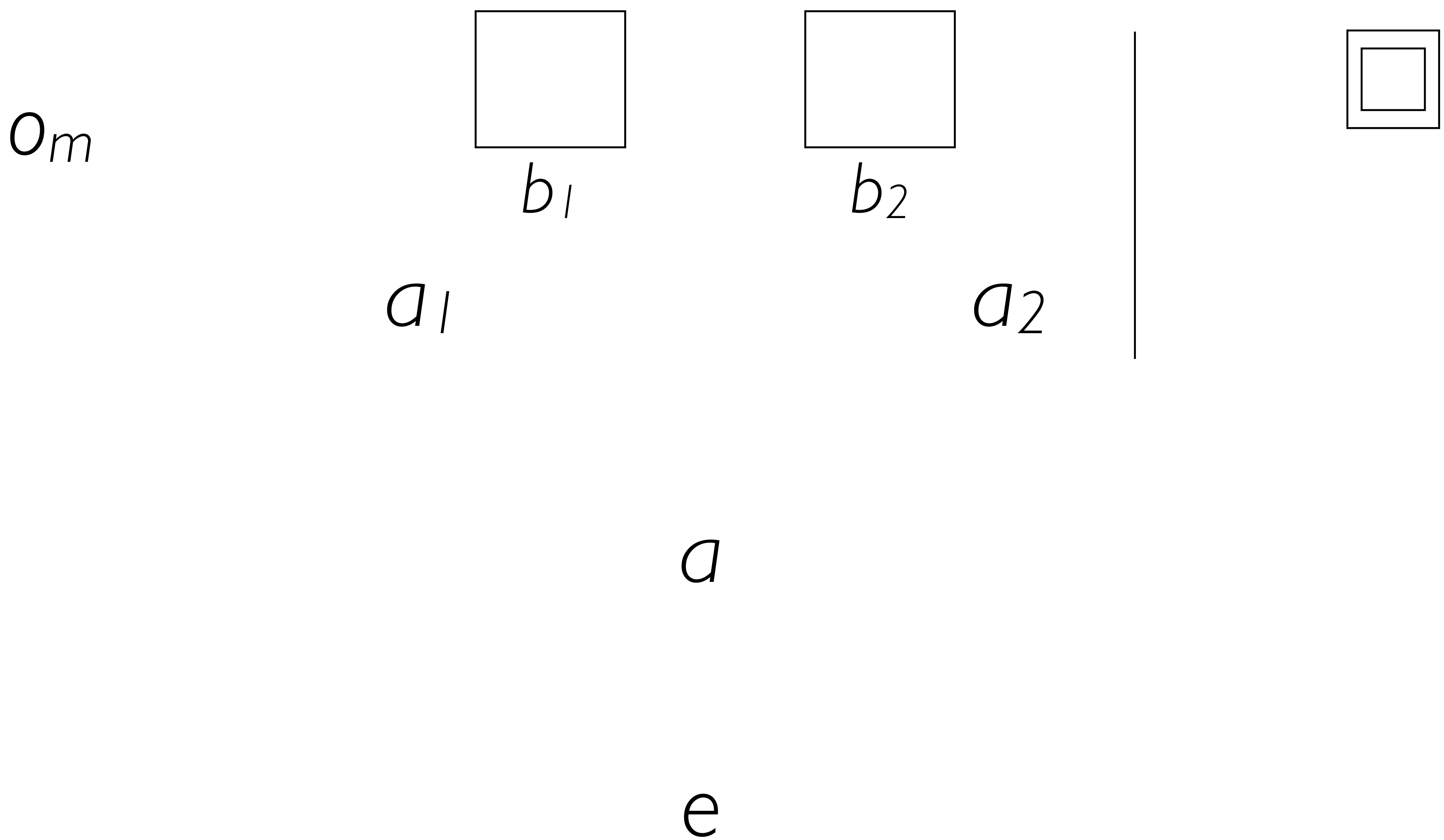


q a formula in modal $\mathscr{L}^n$

Framework for FBT^1_2

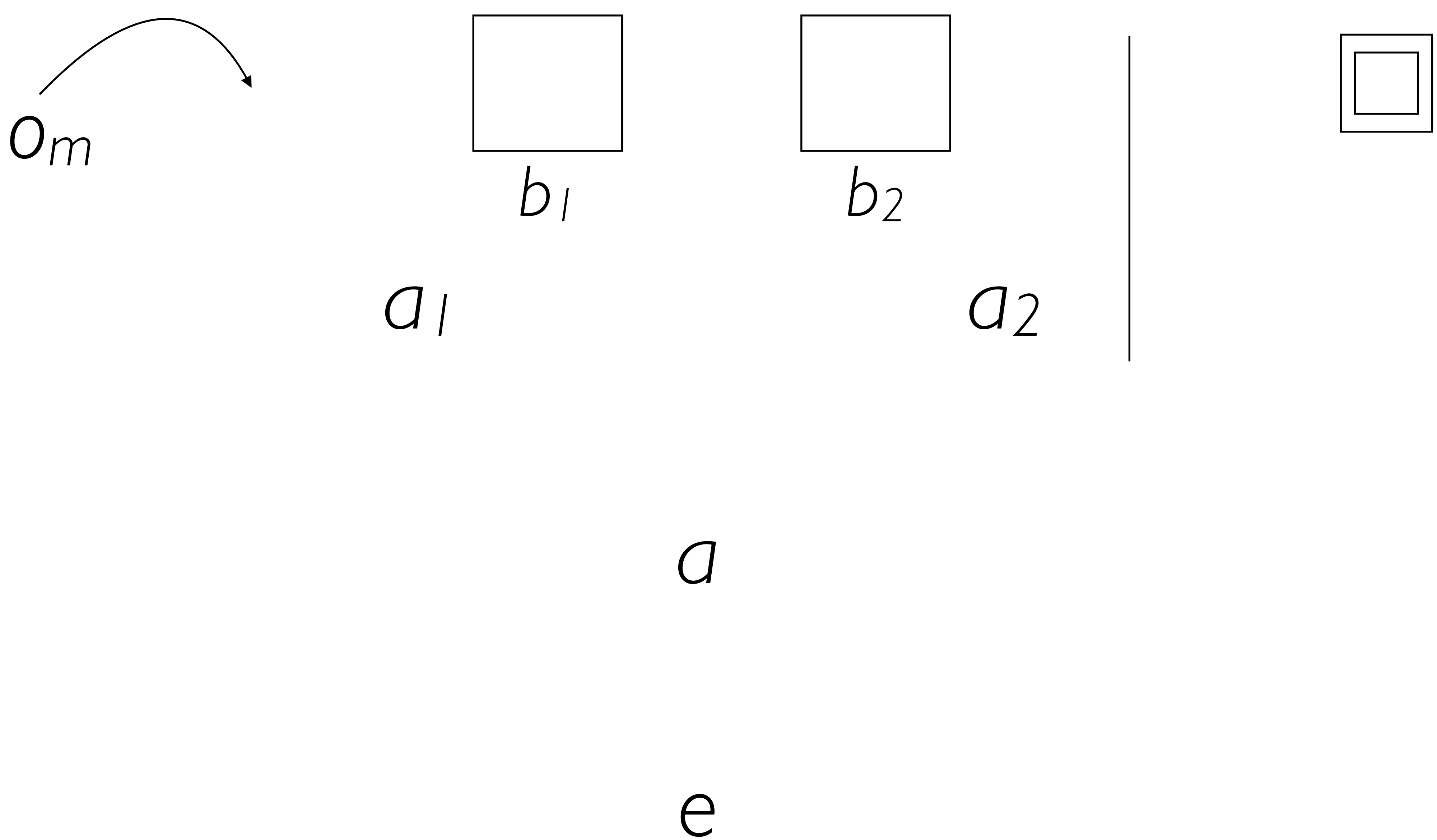


Framework for FBT^1_2
(seven timepoints)

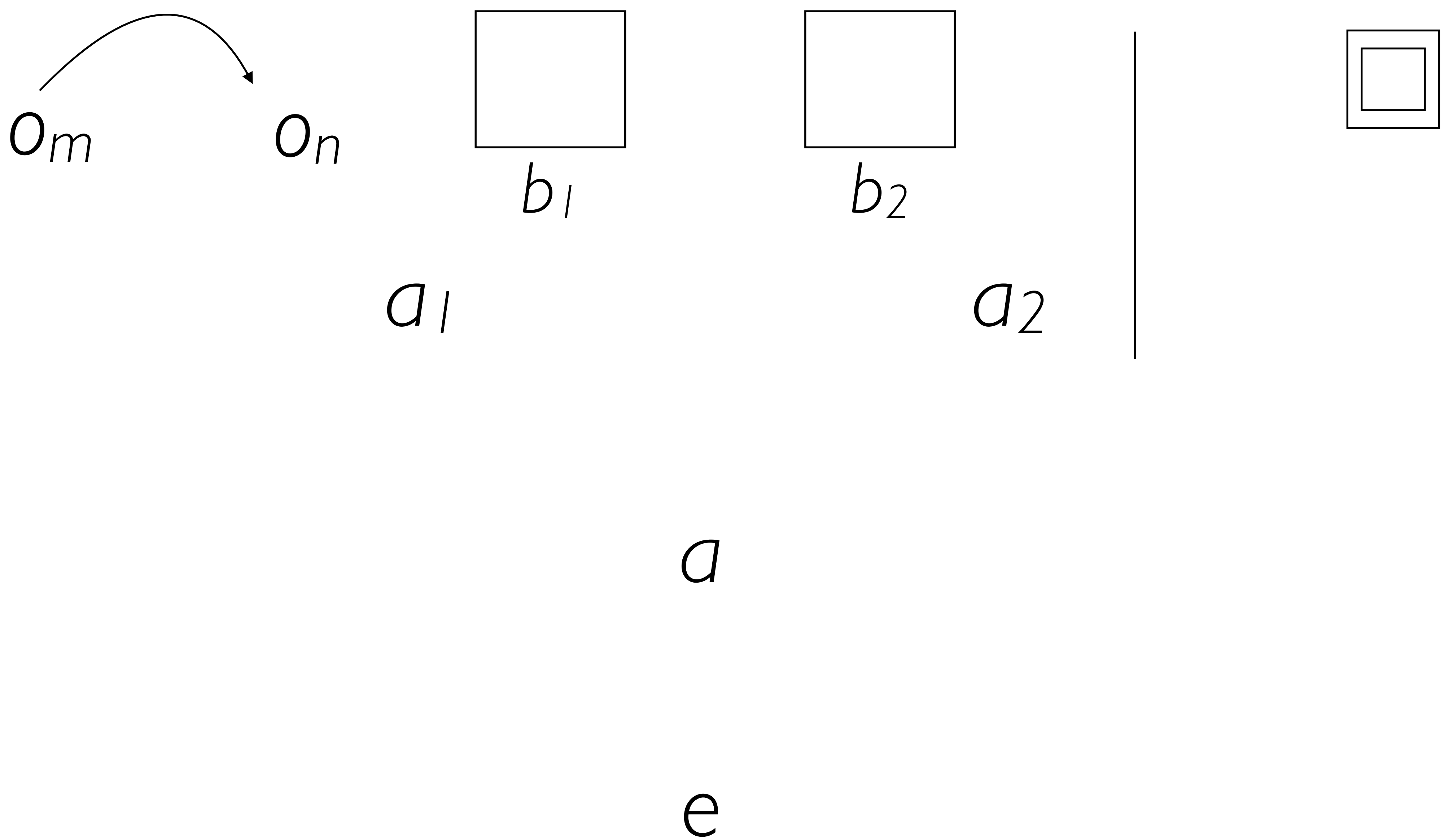


Framework for FBT^1_2

(seven timepoints)

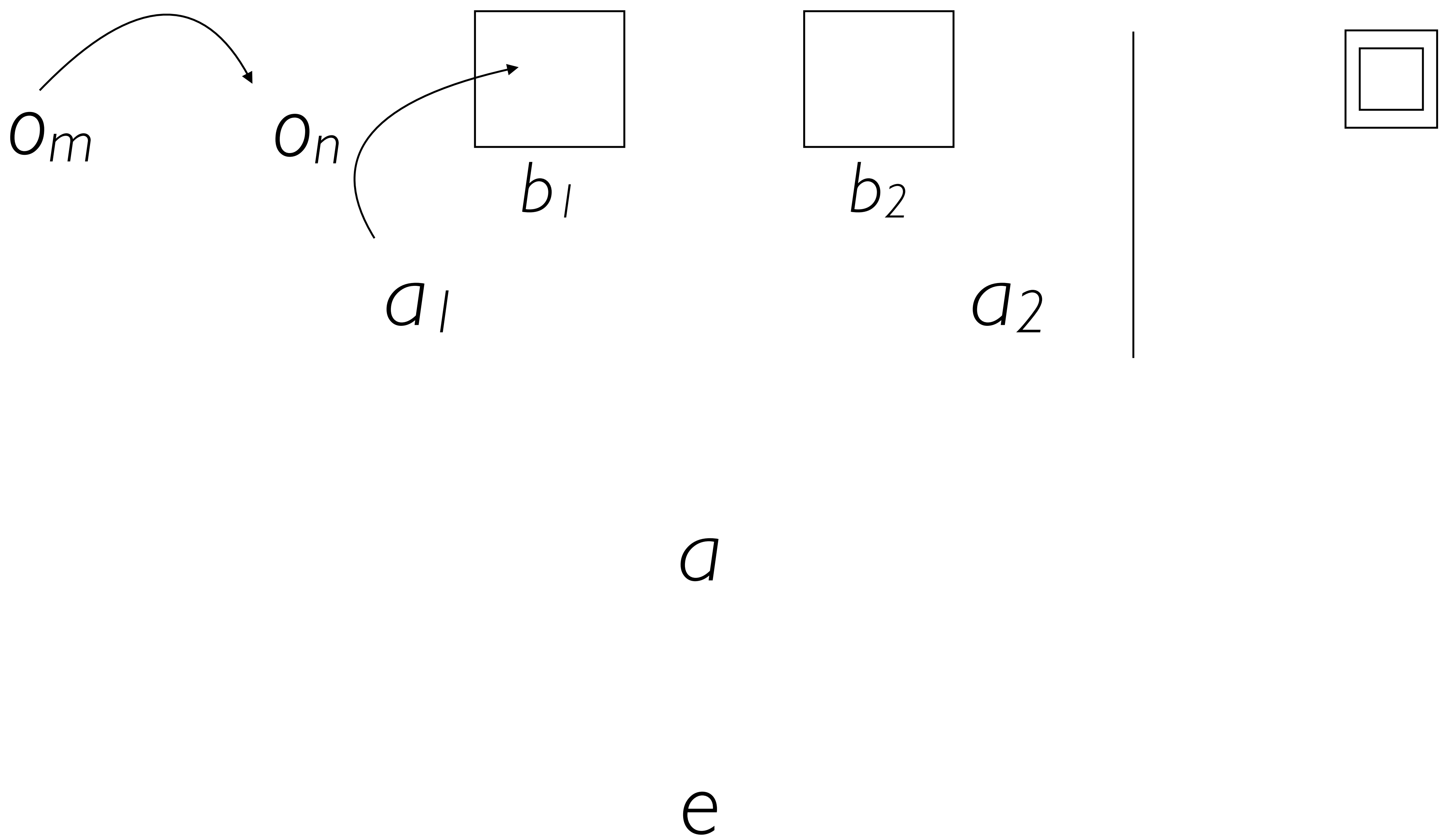


Framework for FBT$^{1}_{2}$
(seven timepoints)



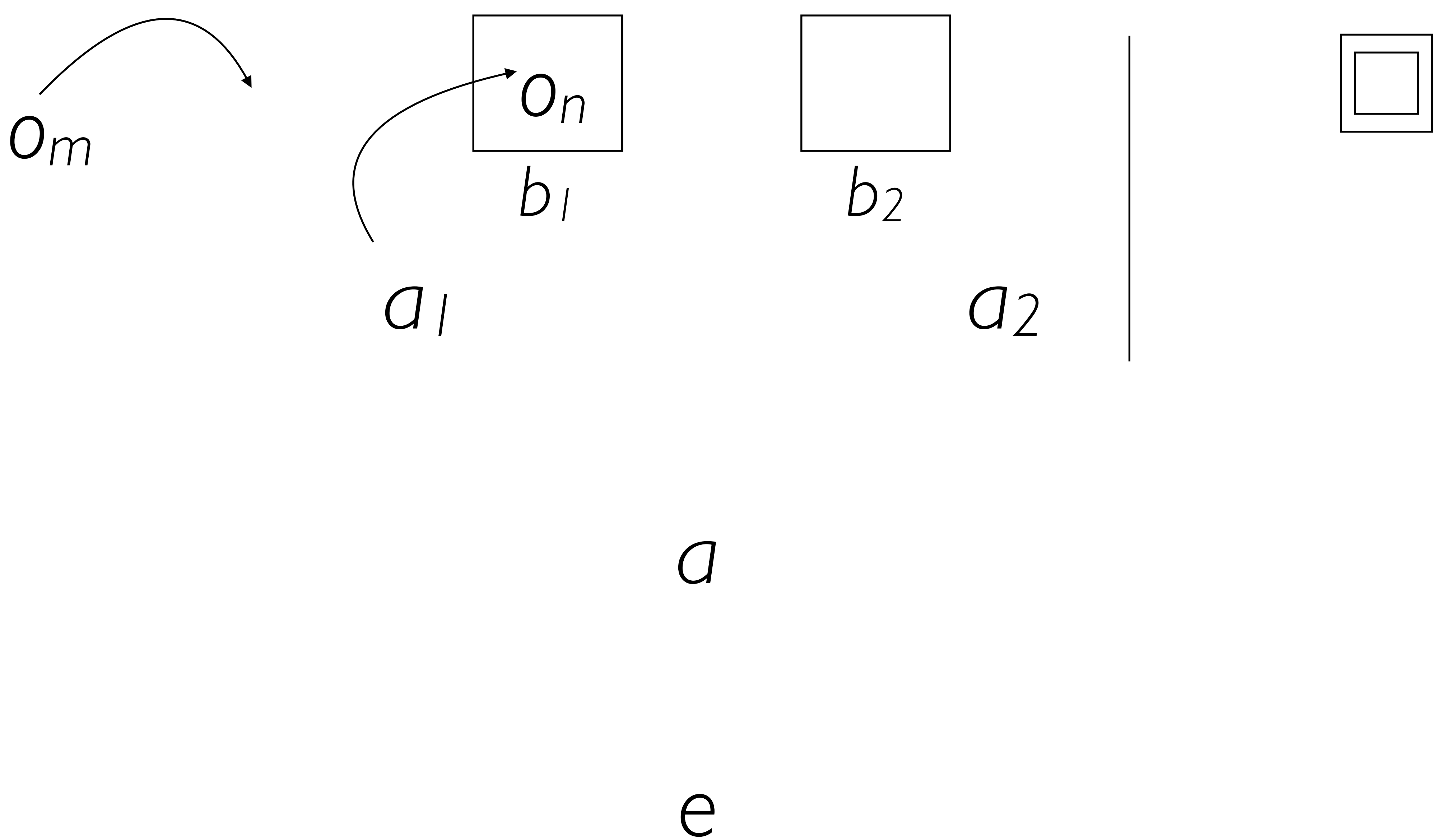
Framework for $FBT^1{}_2$

(seven timepoints)



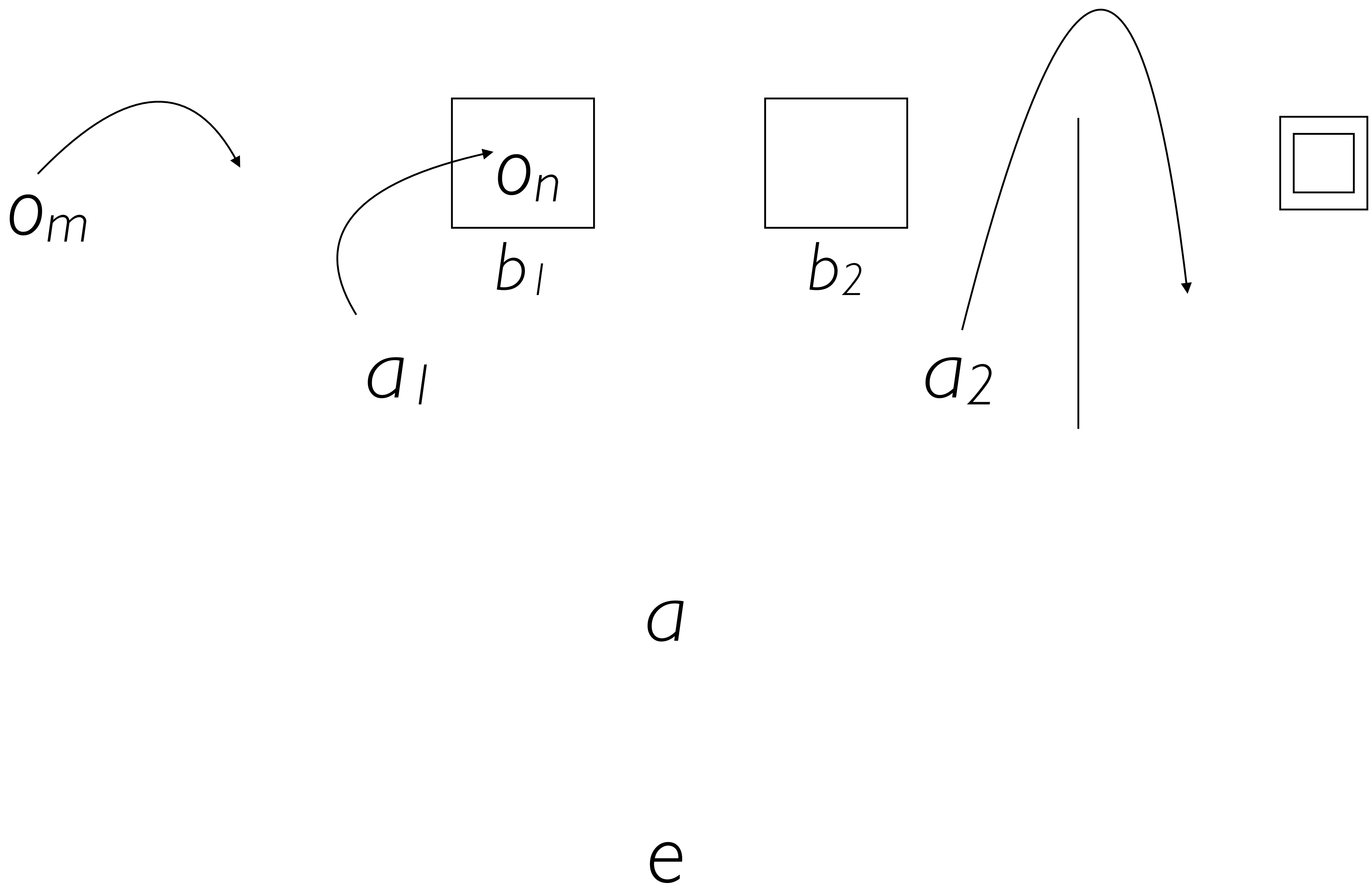
Framework for FBT$^1_2$

(seven timepoints)



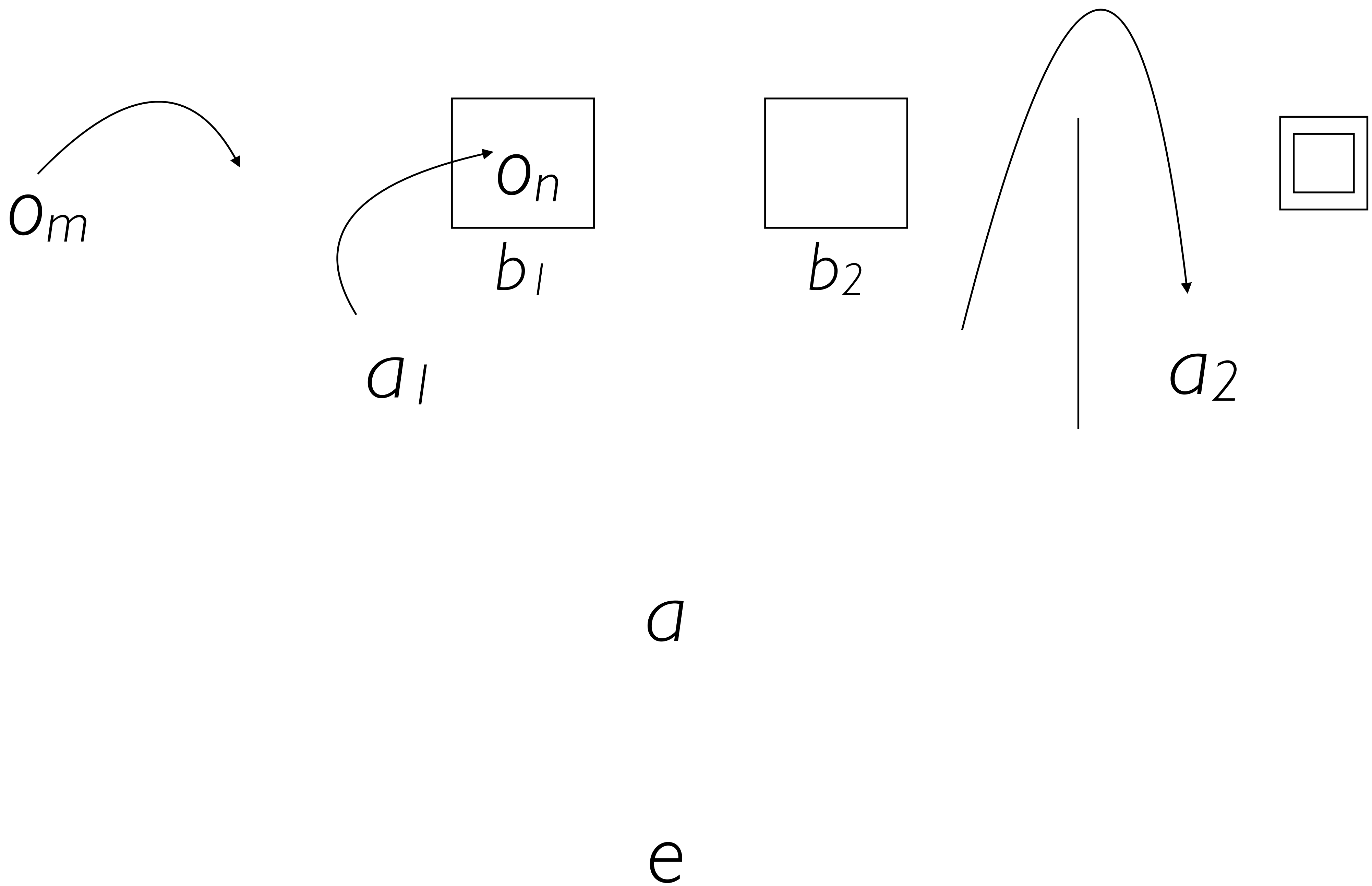
Framework for FBT$^1{}_2$

(seven timepoints)



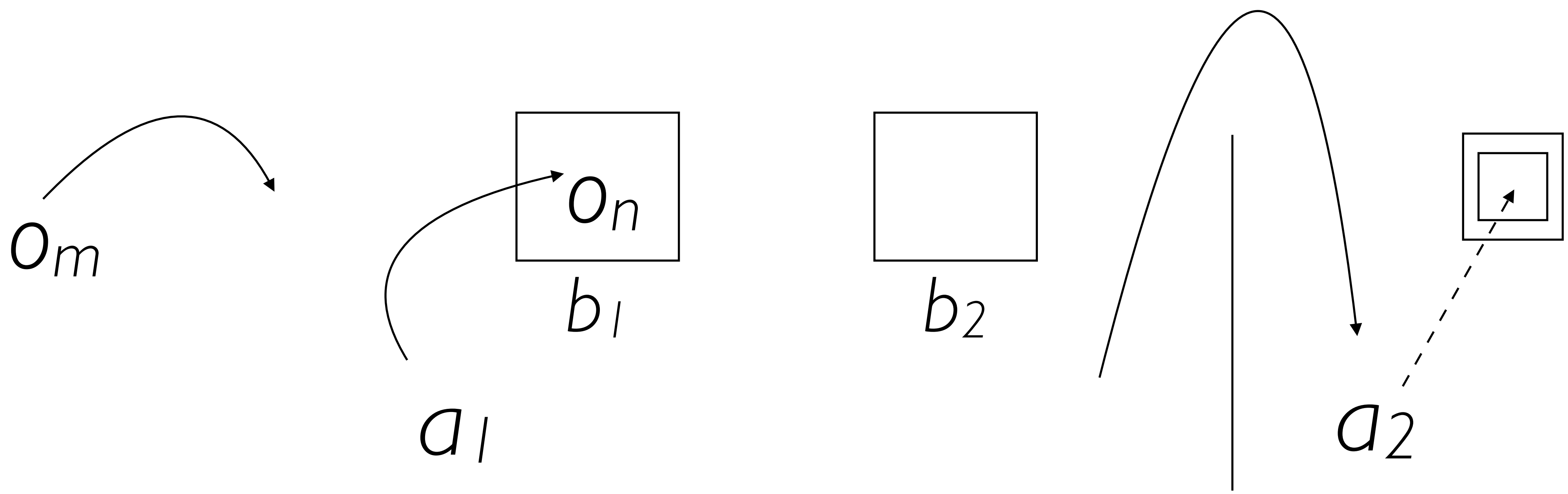
Framework for FBT$^1_2$

(seven timepoints)



Framework for FBT$^1{}_2$

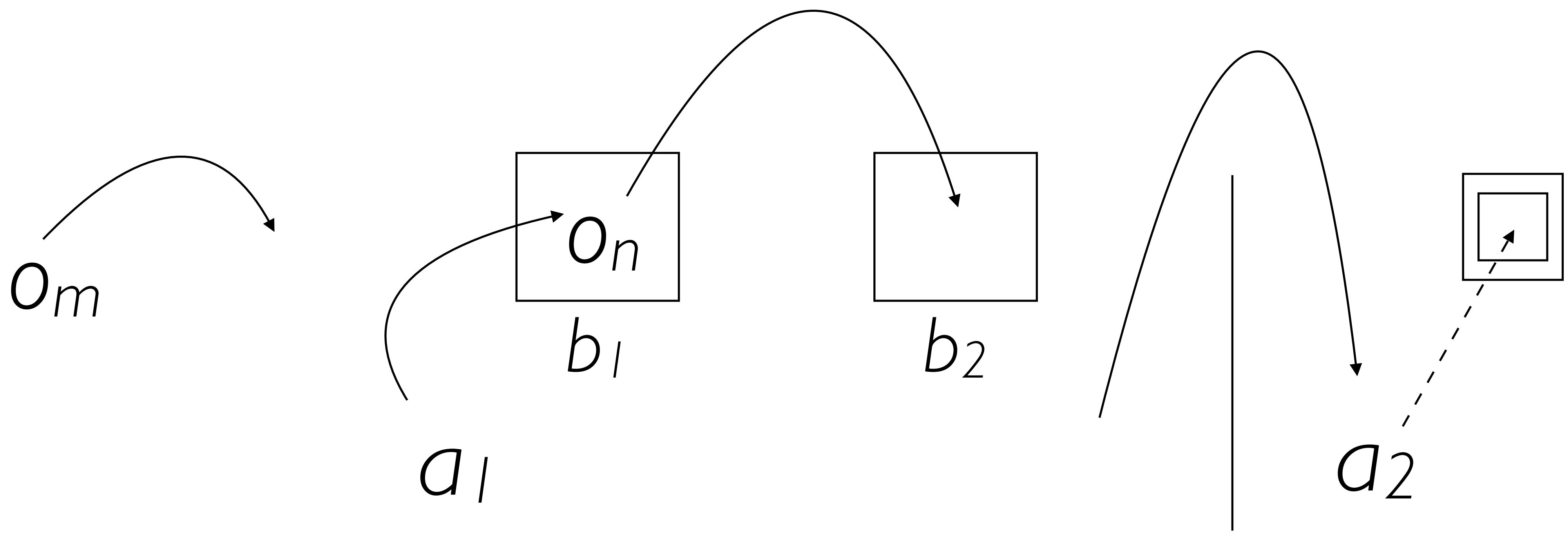
(seven timepoints)



a

e

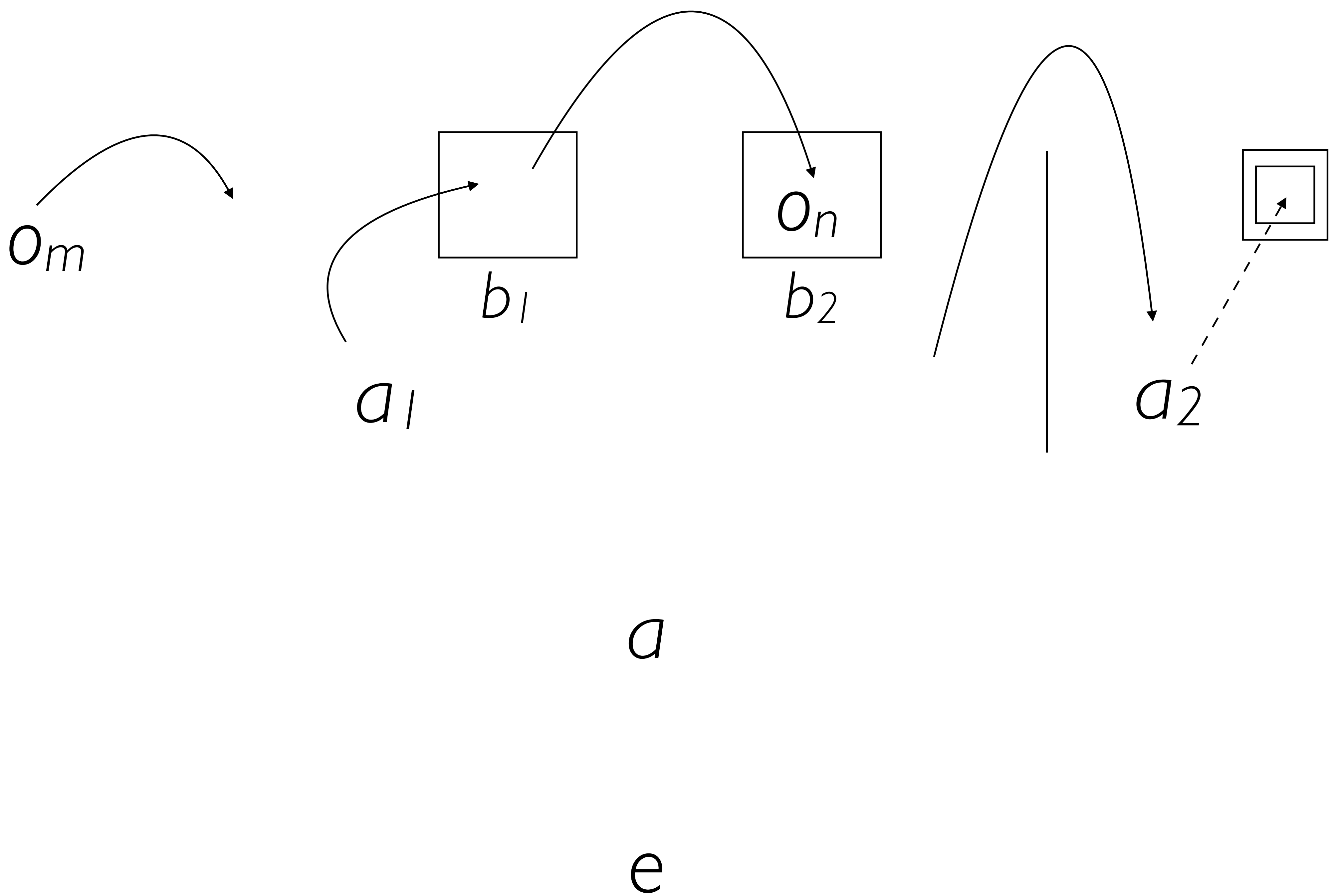
Framework for FBT$^{1}_{2}$
(seven timepoints)



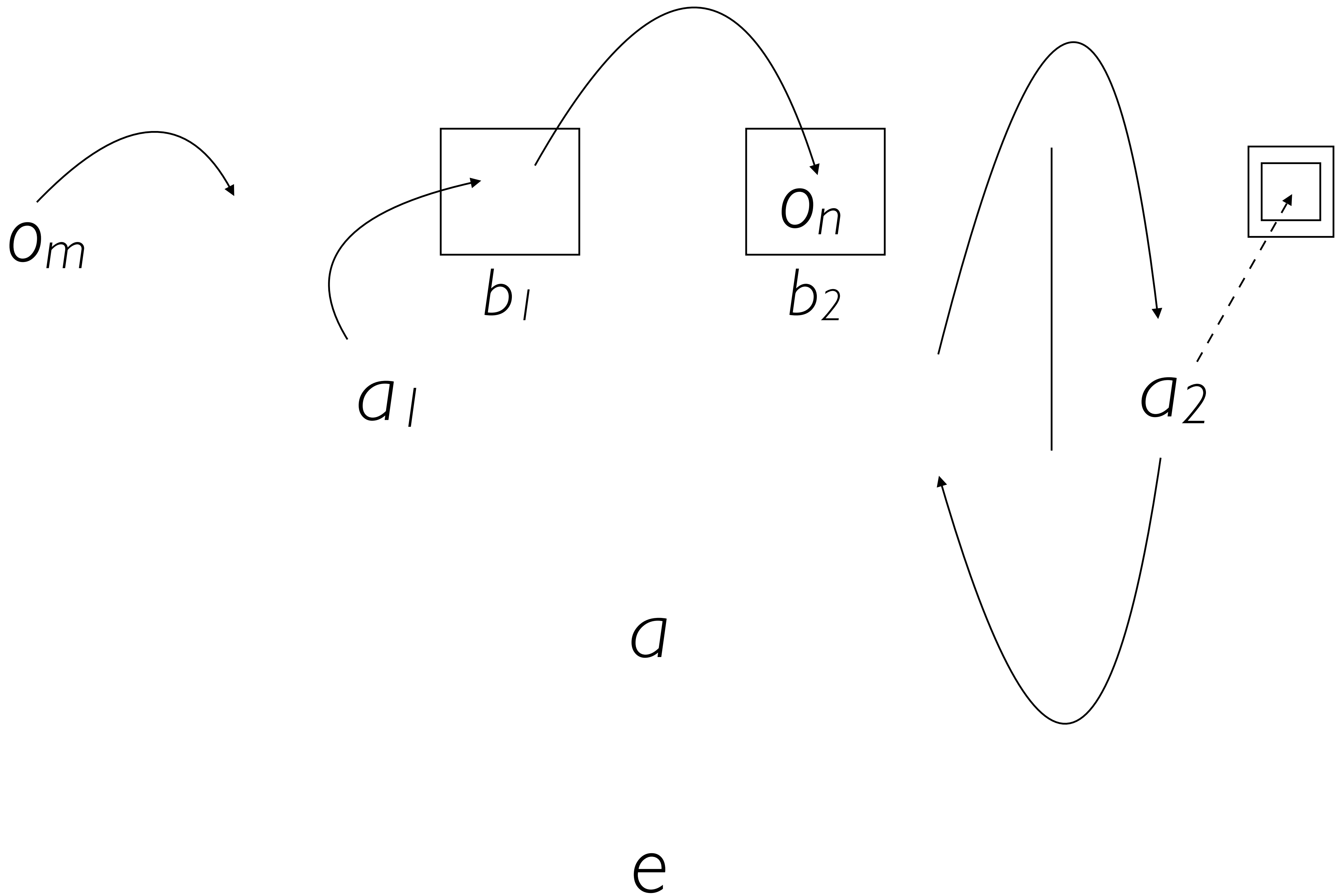
a

e

Framework for $FBT^1{}_2$
(seven timepoints)

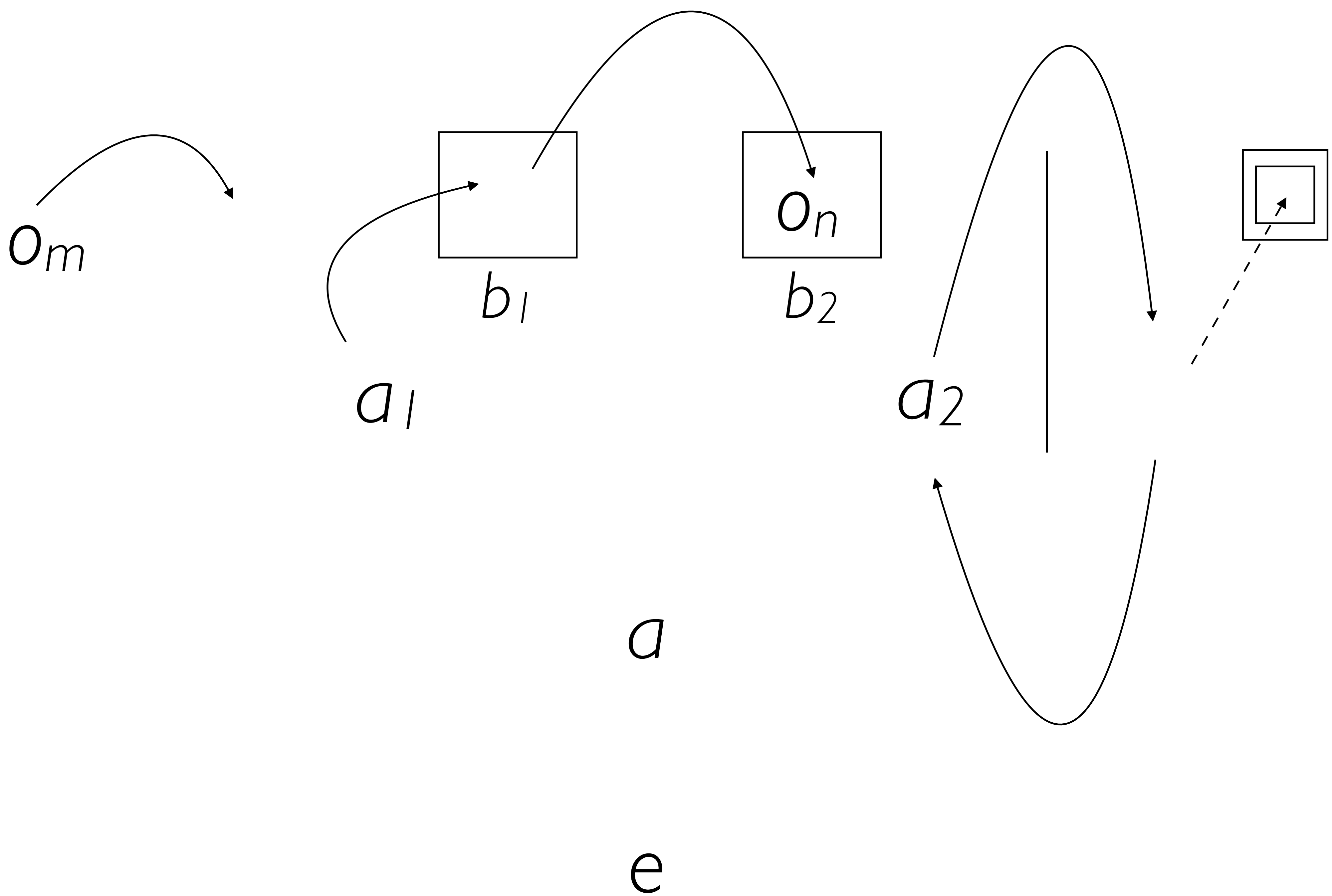


Framework for FBT^1_2
(seven timepoints)

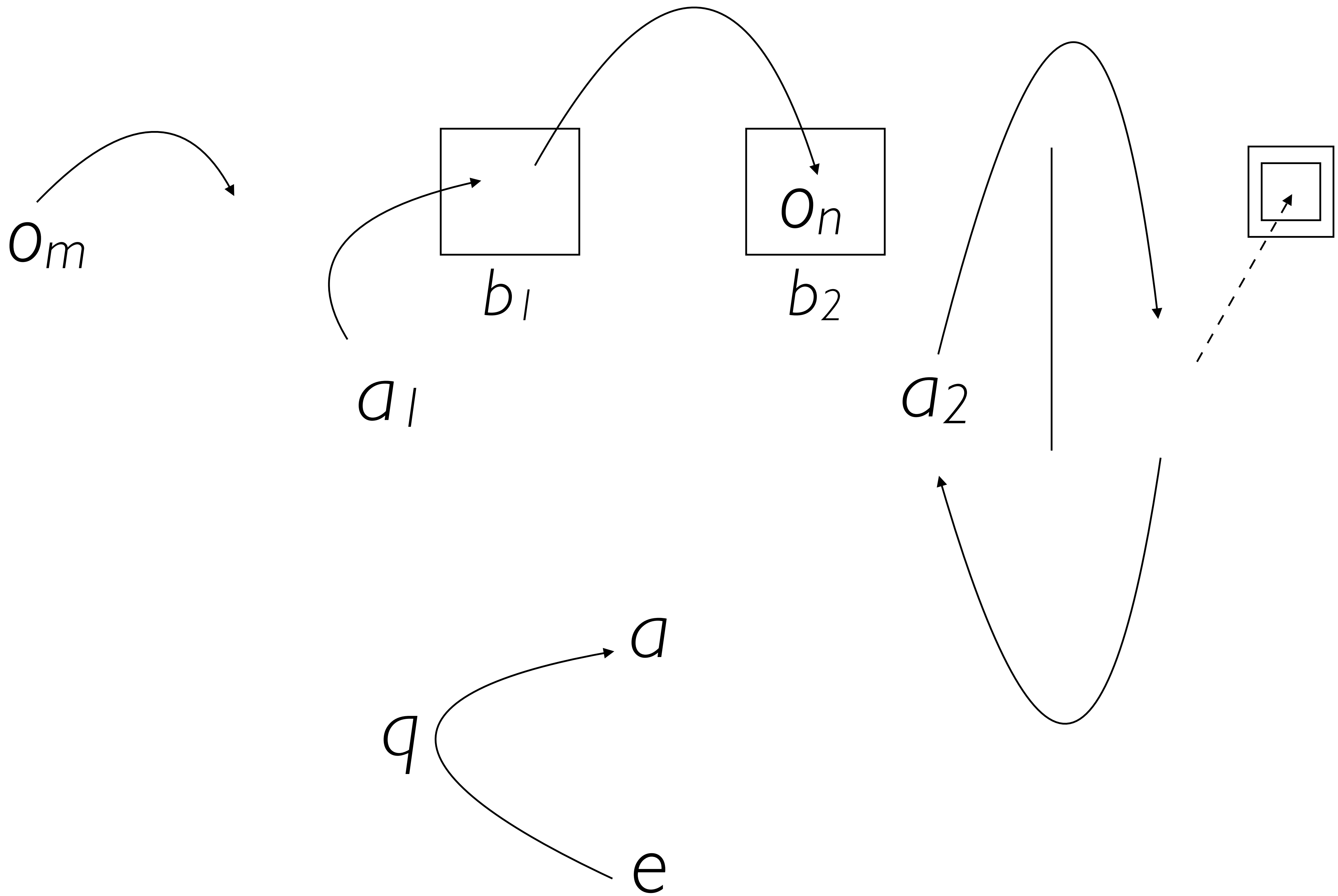


Framework for $FBT^1{}_2$

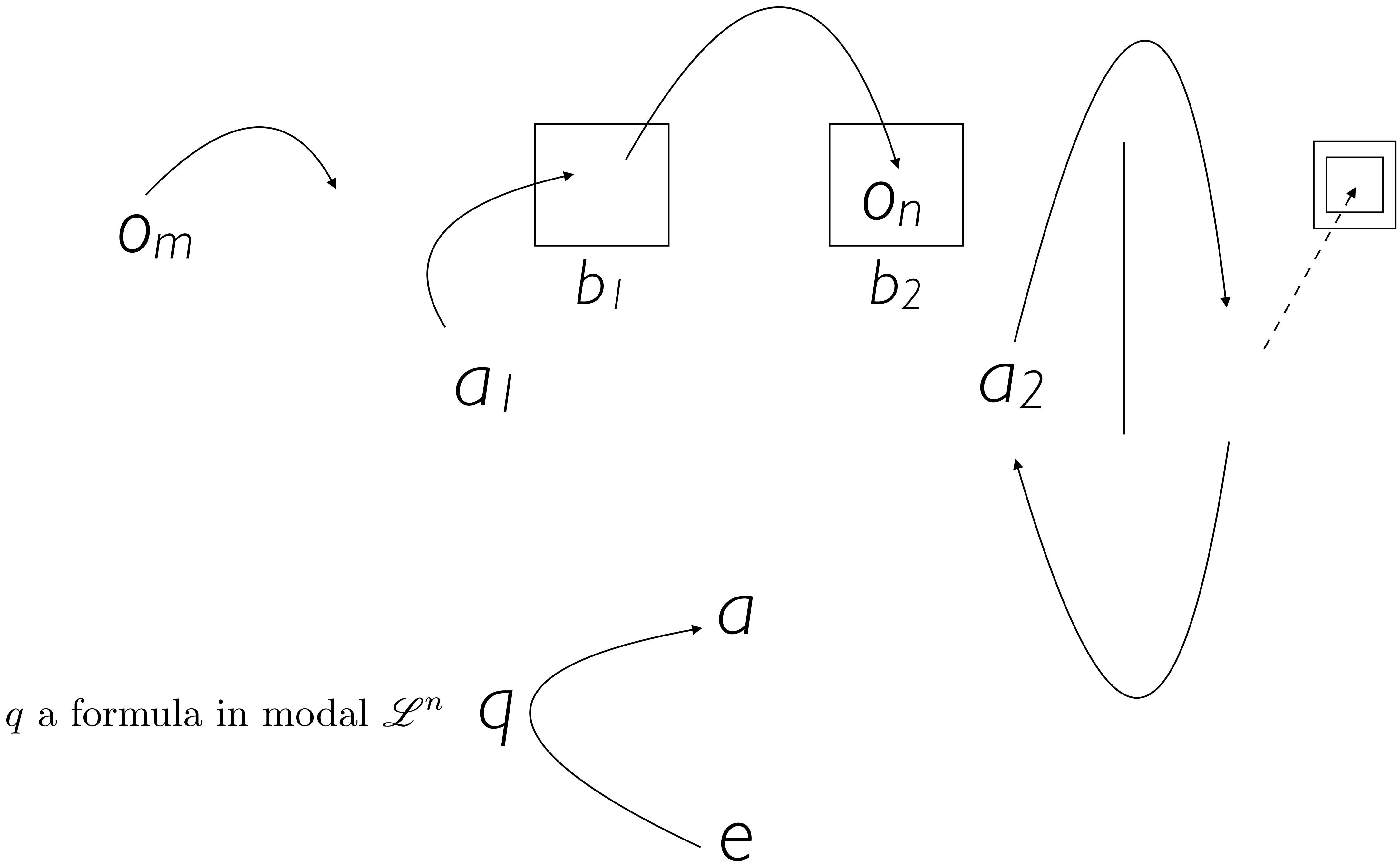
(seven timepoints)



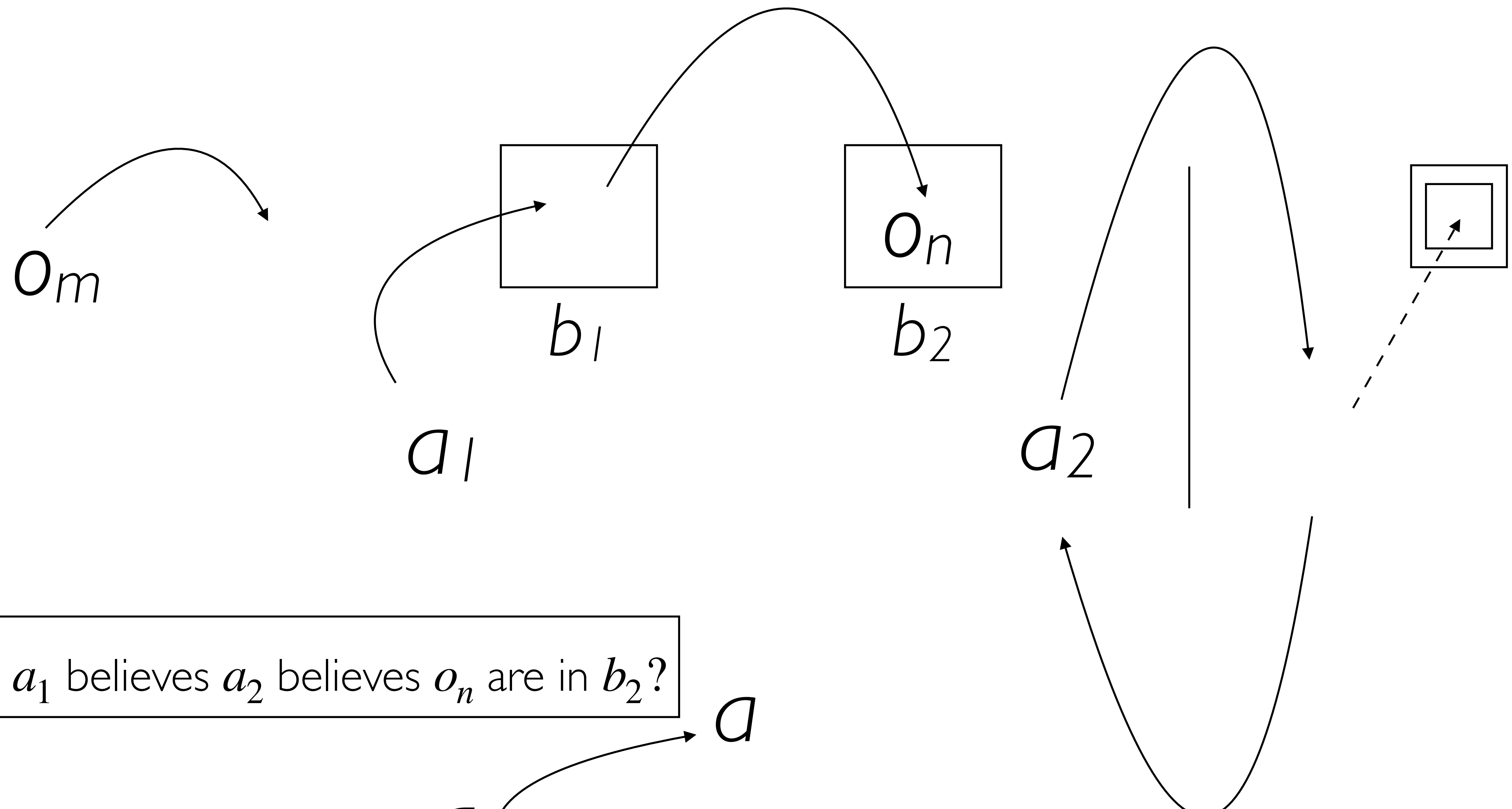
Framework for FBT$^1{}_2$
(seven timepoints)



Framework for FBT$^1{}_2$
(seven timepoints)

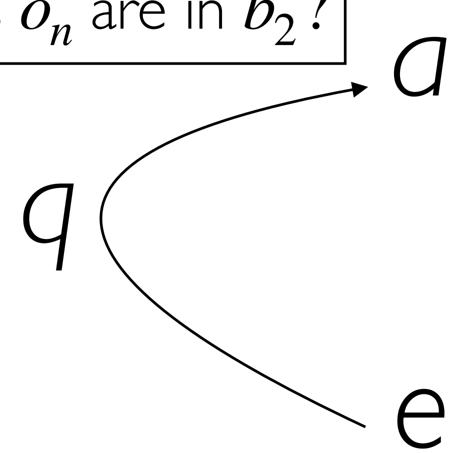


Framework for FBT^{1}_{2}
(seven timepoints)



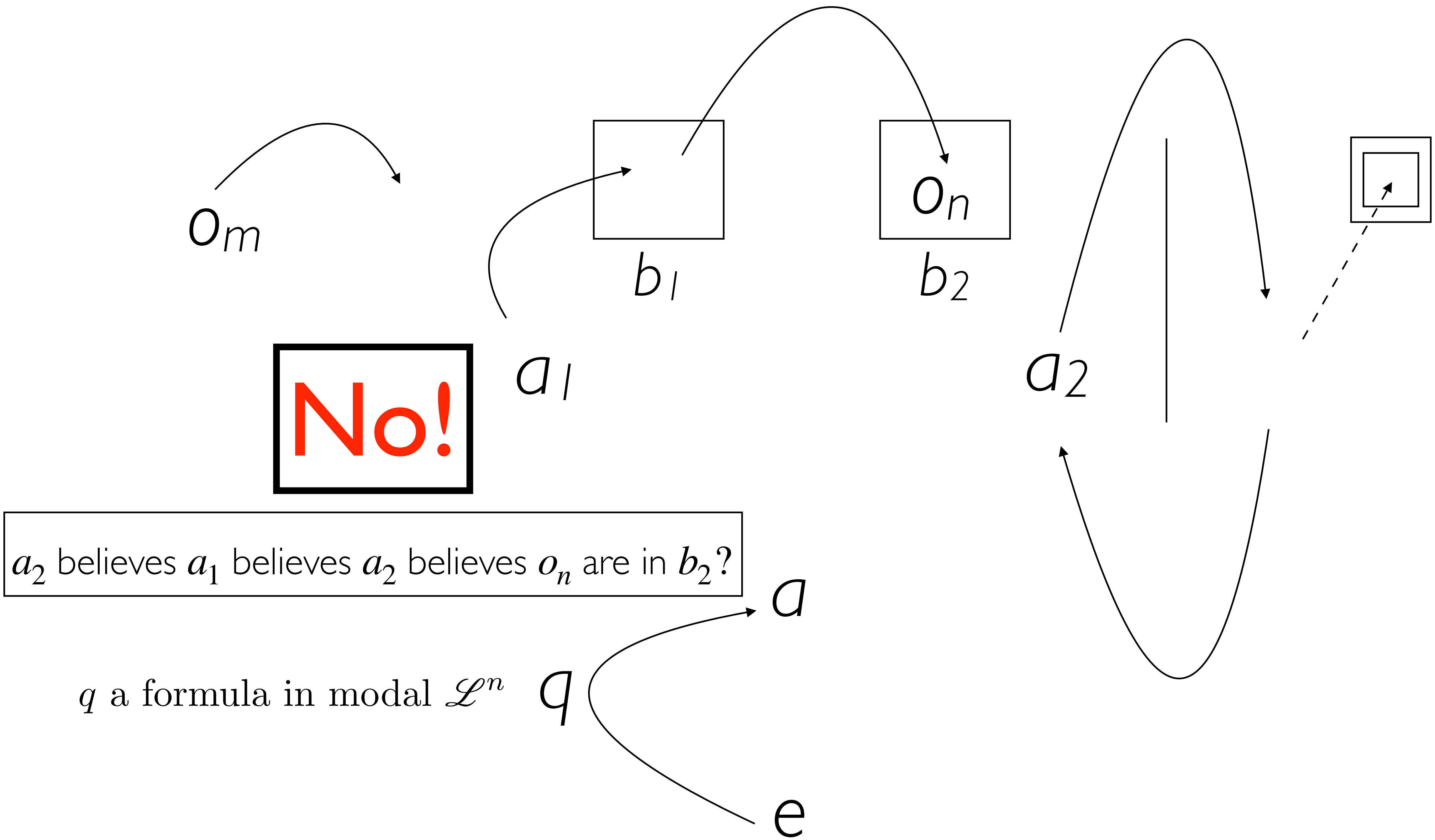
a_2 believes a_1 believes a_2 believes o_n are in b_2?

q a formula in modal $\mathscr{L}^n$



Framework for FBT^1_2

(seven timepoints)



3

Pop Quiz(es)

Pop Quiz(es)

What task, given to capuchin monkeys, chimpanzees, and children, has been claimed by some psychologists to show that **hierarchical reasoning** can in fact be carried out (and in some cases better) by nonhuman animals?

Pop Quiz(es)

What task, given to capuchin monkeys, chimpanzees, and children, has been claimed by some psychologists to show that **hierarchical reasoning** can in fact be carried out (and in some cases better) by nonhuman animals?

Secondly: What do PHP say to (apparently) demolish this claim?

PHP’s Main Thesis?

PHP's Main Thesis?

Notwithstanding the broad comparative consensus arrayed against us, the hypothesis we will be proposing in the present paper is that Darwin was mistaken: The profound biological continuity between human and nonhuman animals masks an equally profound functional discontinuity between the human and nonhuman mind. Indeed, we will argue that the functional discontinuity between human and nonhuman minds pervades nearly every domain of cognition — from reasoning about spatial relations to deceiving conspecifics — and runs much deeper than even the spectacular scaffolding provided by language or culture alone can explain. (p 110)

More specifically?

More specifically?

[a]lthough human and nonhuman animals share many similar cognitive mechanisms, our relational reinterpretation hypothesis (RR) is that only human animals possess the representational processes necessary for systematically reinterpreting first-order perceptual relations in terms of higher-order, role-governed relational structures akin to those found in a ( ). (p 111)

More specifically?

[a]lthough human and nonhuman animals share many similar cognitive mechanisms, our relational reinterpretation hypothesis (RR) is that only human animals possess the representational processes necessary for systematically reinterpreting first-order perceptual relations in terms of higher-order, role-governed relational structures akin to those found in a physical symbol system (   ). (p 111)

More specifically?

[a]lthough human and nonhuman animals share many similar cognitive mechanisms, our relational reinterpretation hypothesis (RR) is that only human animals possess the representational processes necessary for systematically reinterpreting first-order perceptual relations in terms of higher-order, role-governed relational structures akin to those found in a physical symbol system (PSS). (p 111)

What is a PSS? …

Hummel: “Cognitive discontinuity holds. We’re unique.”

Hummel: “Cognitive discontinuity holds. We’re unique.”

Bringsjord: “I’m inclined to agree — but can you prove it?”

Hummel: “Cognitive discontinuity holds. We’re unique.”

Bringsjord: “I’m inclined to agree — but can you prove it?”


The 28th Modern Artificial Intelligence and Cognitive Science Conference

MAICS 2017

April 28-29, 2017
Indiana University/Purdue University – Fort Wayne (IPFW)
Fort Wayne, IN

The MAICS conference traditionally serves as a small but vital forum in the wide range of endeavors that relate to Machine Intelligence and Cognitive Science. Young and old, faculty, researchers, and students can test out ideas, report results, and learn what other people are doing in related fields. You can describe your own interesting research in progress. Graduate students and junior faculty are especially encouraged to submit papers. All submitted papers are peer reviewed for the proceedings publication and conference presentations, and reviewers are encouraged to provide helpful guidance to beginning authors. MAICS provides a friendly complement to more specialized conferences, while fostering quality scholarship.

This year’s theme is **Hybrid Human/Machine Reasoning**. A special track will be created for papers focusing on human reasoning, machine reasoning, and work allowing the two to complement and augment, rather than replace, each other. This is an active area in cognitive science, AI, and many recent funding areas. Keynote speakers specializing in this theme will be invited. Submissions are not, however, required to fit this theme.

IMPORTANT DATES

Submissions: Jan. 15 – Feb. 15, 2017
Notifications: March 5, 2017
Revised submissions: March 15, 2017
Early registration: Feb. 15 – Apr. 5, 2017
Conference: April 28-29, 2017

SUBMISSIONS

We are accepting either full papers (5-8 pages) or poster abstracts (up to 2 pages). Conference proceedings will be published and archived in CEUR-WS, and indexed by DBLP.

KEYNOTE SPEAKERS

Selmer Bringsjord, RPI – “Inaugurating the Formal Science of Darwin’s Mistake”

John E. Hummel, UIUC – “What Happened to the Human Brain?”

See the talk abstracts here:
http://users.ipfw.edu/licatoj/maics/keynote.pdf

TOPICS OF INTEREST

We invite submissions centered around, but not limited to:

- Hybrid Human/Machine Reasoning
- Robotics
- Semantic Web
- Data Mining & Visualization
- Evolutionary Computation
- Soft Computing
- Neural Networks
- Machine Learning
- Gaming
- Cybersecurity
- HCI and HRI
- Cognitive Psychology
- Developmental Psychology
- Psychology of Reasoning
- Neuroscience
- Logic-based AI
- Machine Reasoning
- Computational Linguistics
- Uncertainty in reasoning
- Any area of cognitive science or artificial intelligence

For more information: http://ipfw.edu/maics
Contact: MAICS@ipfw.edu


The 28th Modern Artificial Intelligence and Cognitive Science Conference

MAICS 2017

April 28-29, 2017
Indiana University/Purdue University – Fort Wayne (IPFW)
Fort Wayne, IN

KEYNOTE SPEAKERS

Dr. Selmer Bringsjord
Chair of Cognitive Science Department, Rensselaer Polytechnic Institute
Director of the Rensselaer AI and Reasoning (RAIR) Lab

“Inaugurating the Formal Science of Darwin’s Mistake”

In their bold "Darwin's Mistake," Penn, Holyoak, & Povinelli (PHP; 2008) argue that Darwin profoundly erred in holding that there is no discontinuity between the cognitive capacities of nonhuman animals (e.g. dogs, the cognitive powers of which he repeatedly exalted, and also e.g. chimpanzees) versus those of *Homo sapiens.*[1] Predictably, many refuse to concede that PHP are right. This debate, which continues, is to this point in time a decidedly and thoroughly *informal* affair --- one based in part on evidence, yes; and indeed evidence that comes at least in part from science, but from *empirical* science (comparative psychology, mostly). I begin to recast the debate in the language of the *formal* sciences, which are based directly on formal logic and mathematics and are theorem-driven. The ultimate upshot expected from this recasting is the result that Darwin's continuity position, which is the very foundation of his *Descent of Man*, is *provably* wrong. My recasting, among other things, supplants PHP's reference to "physical symbol systems" with formalisms used in order to be precise about what computation is, and supplants helpful talk of various cognitive capacities (e.g., “relational reasoning”) with precise forms of reasoning over rigorous defined formulas and equations.

[1] I have long maintained that Darwin’s /Descent of Man/ is painfully illogical. See e.g. “How Logical is Darwin’s /Descent of Man” (2009): http://kryten.mm.rpi.edu/PRES/DESCENT111909/SB_Darwin_Descent.pdf. A nd I have pointed out that Pinker’s reply to Wallace’s Paradox, on formal grounds, doesn’t work: see (Bringsjord 2001).

- Bringsjord, S. (2001) “Are We Evolved Computers? A Critical Review of S Pinker’s /How the Mind Works/“ /Philosophical Psychology/ 2: 227—243. A preprint is available at http://kryten.mm.rpi.edu/selmer.wallaceparadox.pdf.
- Darwin, C. (1997/1871) /Descent of Man/ Amherst, NY: Prometheus.
- Penn, D., Holyoak, K. & Povinelli, D. (2008) "Darwin's Mistake: Explaining the Discontinuity Between Human and Nonhuman Minds" /Behavioral & Brain Sciences/ *31*: 109--178.

Dr. John E. Hummel
Professor of Psychology, University of Illinois at Urbana-Champaign
Director of the Relational Reasoning Laboratory

“What Happened to the Human Brain?”

Humans are unique among the great apes in our capacity to reason explicitly about relations—an ability that underlies our capacity for mathematics, science, engineering and everything else that distinguishes us as a species. Reasoning about relations requires us to represent relations as entities in their own right, to bind arguments to those relations, to map systems of structures based on shared relations and to use the resulting mappings to constrain inference and learning. During human evolution something happened to our brains that makes it possible for us to do these things. I will discuss simulations of how the human brain accomplishes these tasks, and how the resulting algorithms account for aspects of human thinking, especially those that make us unique among the great apes.

For more information: http://ipfw.edu/maics
Contact: MAICS@ipfw.edu

Hummel: “Cognitive discontinuity holds. We’re unique.”

Bringsjord: “I’m inclined to agree — but can you prove it?”

Dr. Selmer Bringsjord

Chair of Cognitive Science Department, Rensselaer Polytechnic Institute
Director of the Rensselaer AI and Reasoning (RAIR) Lab

“Inaugurating the Formal Science of Darwin’s Mistake”

In their bold "Darwin's Mistake," Penn, Holyoak, & Povinelli (PHP; 2008) argue that Darwin profoundly erred in holding that there is no discontinuity between the cognitive capacities of nonhuman animals (e.g. dogs, the cognitive powers of which he repeatedly exalted, and also e.g. chimpanzees) versus those of *Homo sapiens.*[1] Predictably, many refuse to concede that PHP are right. This debate, which continues, is to this point in time a decidedly and thoroughly *informal* affair --- one based in part on evidence, yes; and indeed evidence that comes at least in part from science, but from *empirical* science (comparative psychology, mostly). I begin to recast the debate in the language of the *formal* sciences, which are based directly on formal logic and mathematics and are theorem-driven. The ultimate upshot expected from this recasting is the result that Darwin's continuity position, which is the very foundation of his *Descent of Man*, is *provably* wrong. My recasting, among other things, supplants PHP's reference to "physical symbol systems" with formalisms used in order to be precise about what computation is, and supplants helpful talk of various cognitive capacities (e.g., “relational reasoning”) with precise forms of reasoning over rigorous defined formulas and equations.

[1] I have long maintained that Darwin’s /Descent of Man/ is painfully illogical. See e.g. “How Logical is Darwin’s /Descent of Man” (2009): http://kryten.mm.rpi.edu/PRES/DESCENT111909/SB_Darwin_Descent.pdf. A nd I have pointed out that Pinker’s reply to Wallace’s Paradox, on formal grounds, doesn’t work: see (Bringsjord 2001).

- Bringsjord, S. (2001) “Are We Evolved Computers? A Critical Review of S Pinker’s /How the Mind Works/“ /Philosophical Psychology/ 2: 227—243. A preprint is available at http://kryten.mm.rpi.edu/selmer.wallaceparadox.pdf.
- Darwin, C. (1997/1871) /Descent of Man/ Amherst, NY: Prometheus.
- Penn, D., Holyoak, K. & Povinelli, D. (2008) "Darwin's Mistake: Explaining the Discontinuity Between Human and Nonhuman Minds" /Behavioral & Brain Sciences/ *31*: 109--178.

Dr. John E. Hummel

Professor of Psychology, University of Illinois at Urbana-Champaign
Director of the Relational Reasoning Laboratory

“What Happened to the Human Brain?”

Humans are unique among the great apes in our capacity to reason explicitly about relations—an ability that underlies our capacity for mathematics, science, engineering and everything else that distinguishes us as a species. Reasoning about relations requires us to represent relations as entities in their own right, to bind arguments to those relations, to map systems of structures based on shared relations and to use the resulting mappings to constrain inference and learning. During human evolution something happened to our brains that makes it possible for us to do these things. I will discuss simulations of how the human brain accomplishes these tasks, and how the resulting algorithms account for aspects of human thinking, especially those that make us unique among the great apes.

Selmer: "To start, a PSS is …

Selmer: “To start, a PSS is …

a physicalized computing machine!”

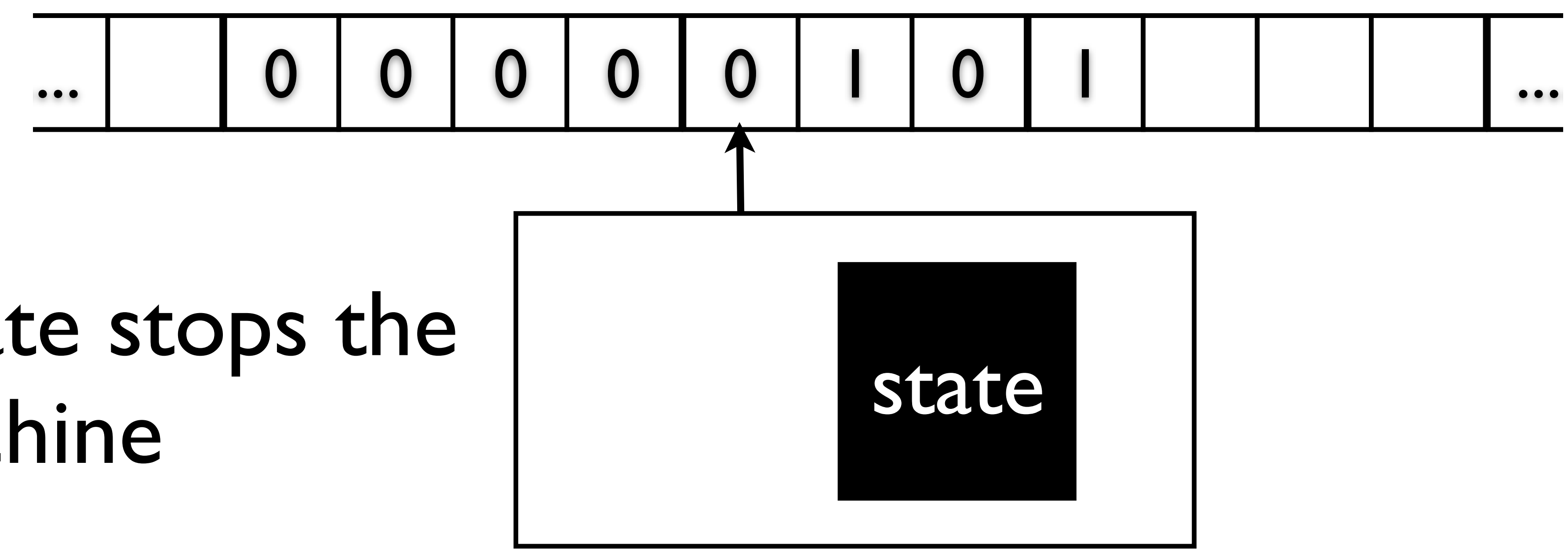
Selmer: “To start, a PSS is …

a physicalized computing machine!”

Okay, and what’s a computing machine?

Turing-decidability/computability …

Turing Machines



a special state stops the machine

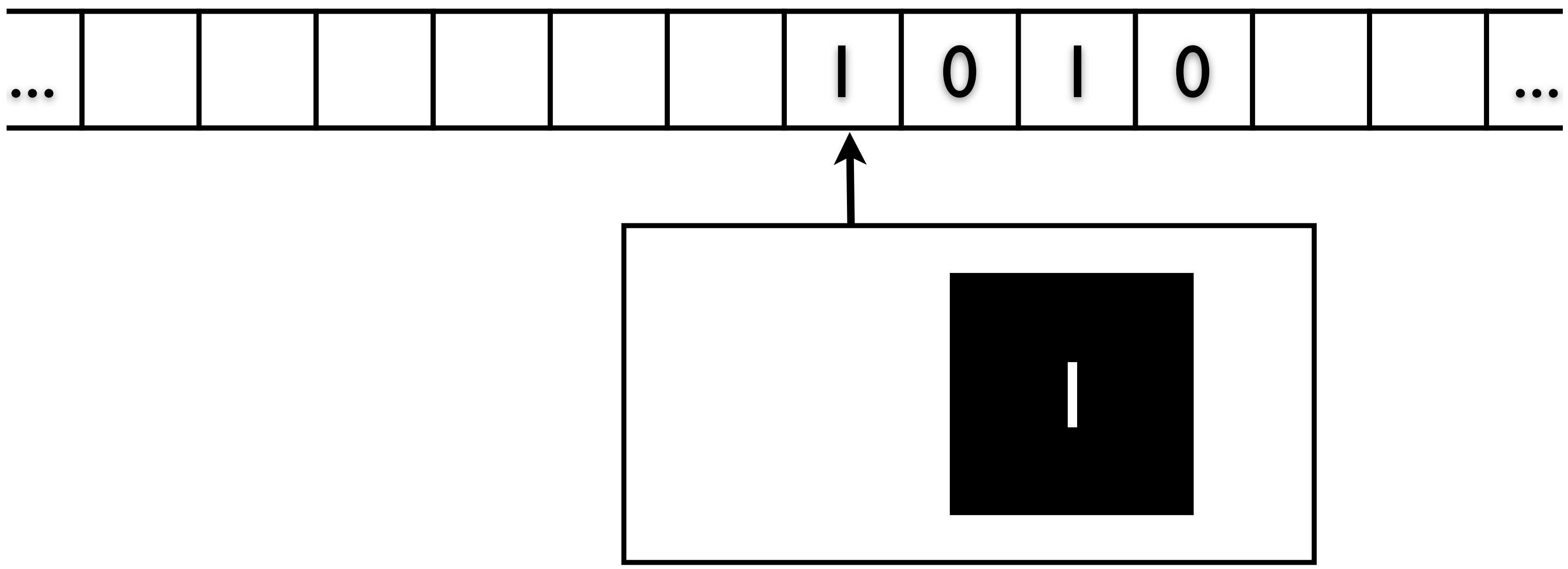
Program

current state	current symbol	next state	next symbol	direction

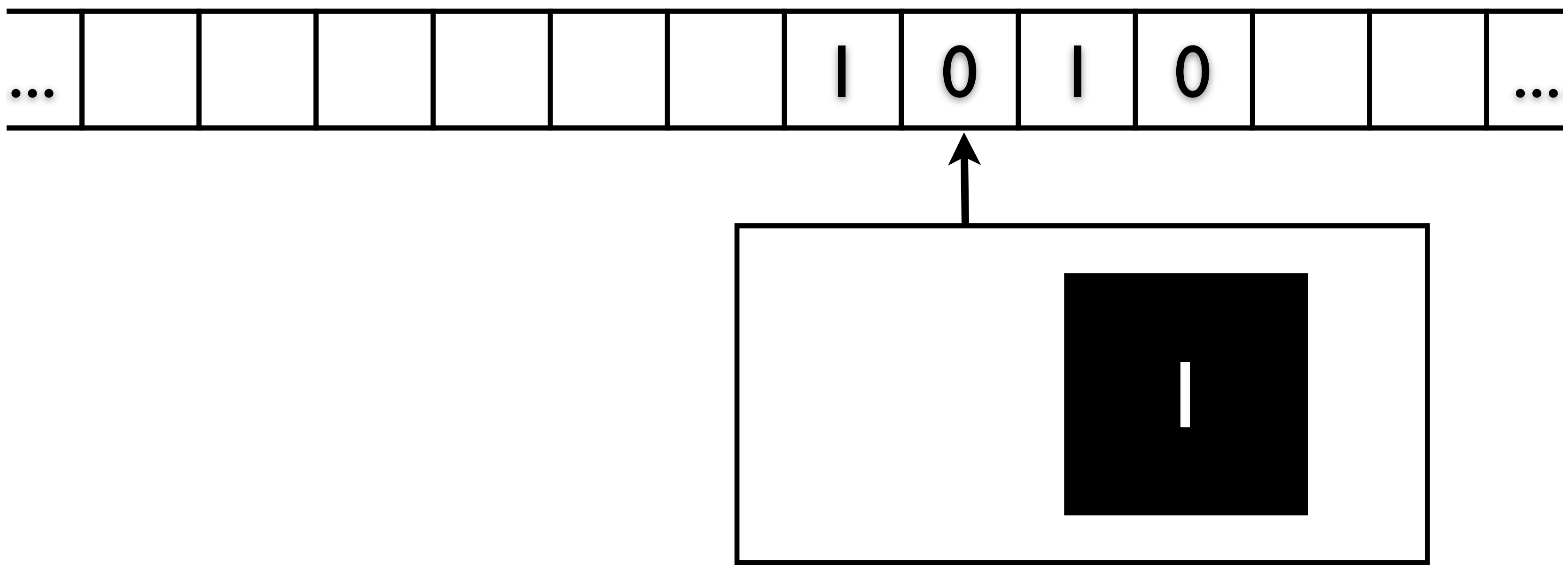
Even Number Function

- $f(n) = 1$ if n is even; else $f(n) = 0$

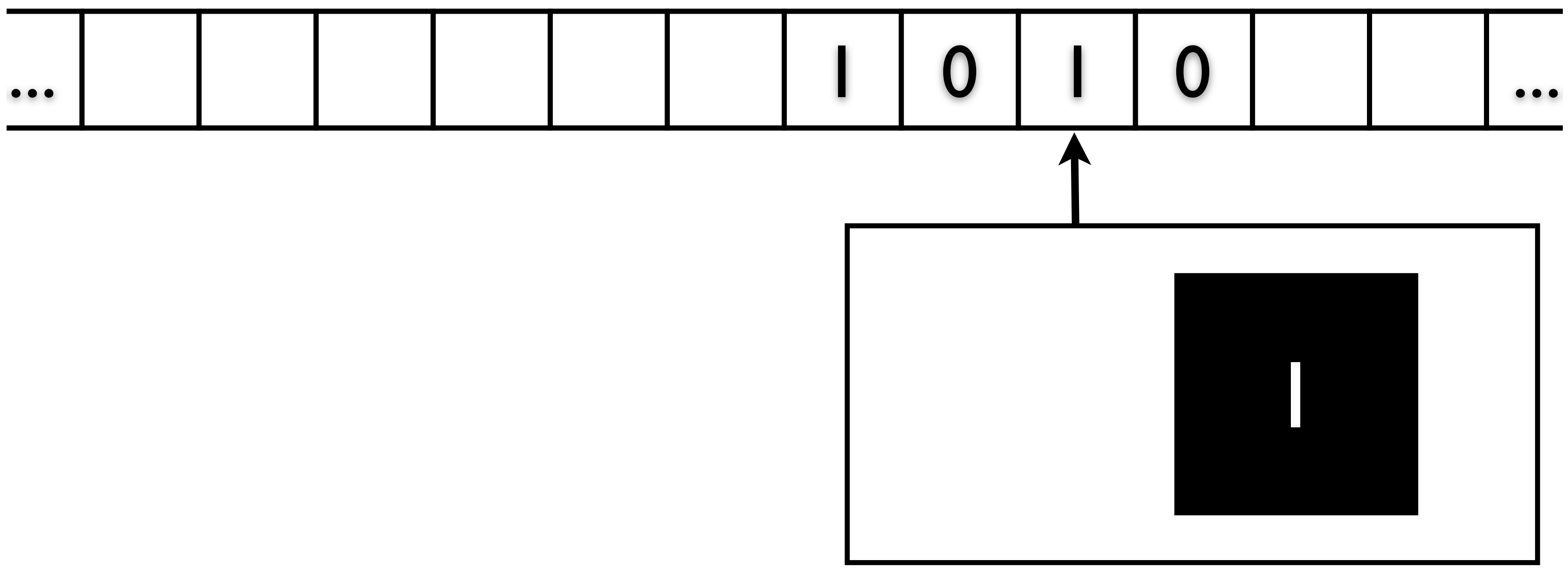
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Same
4	1	3	1	Same



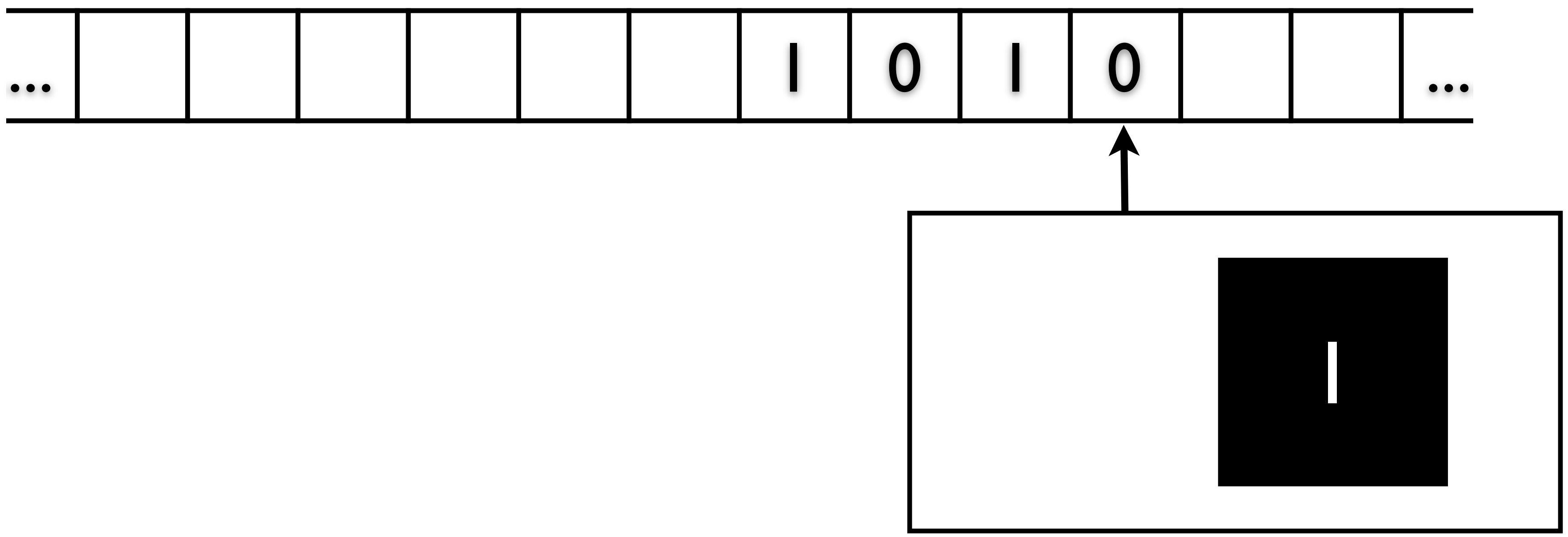
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



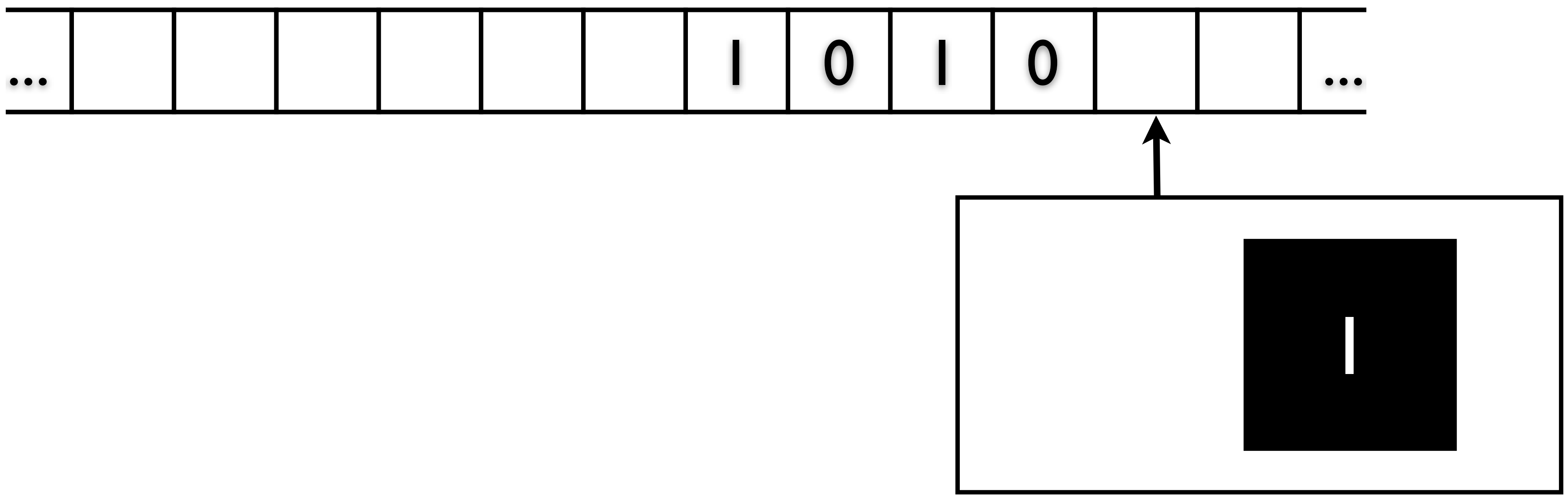
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



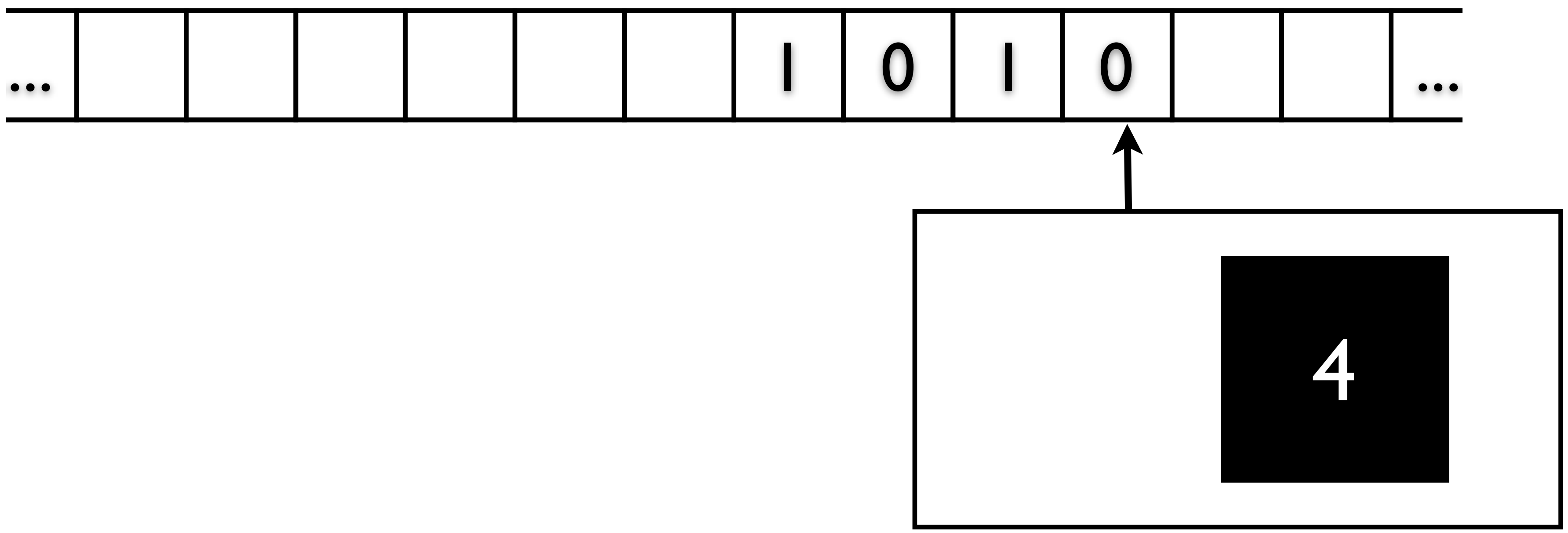
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



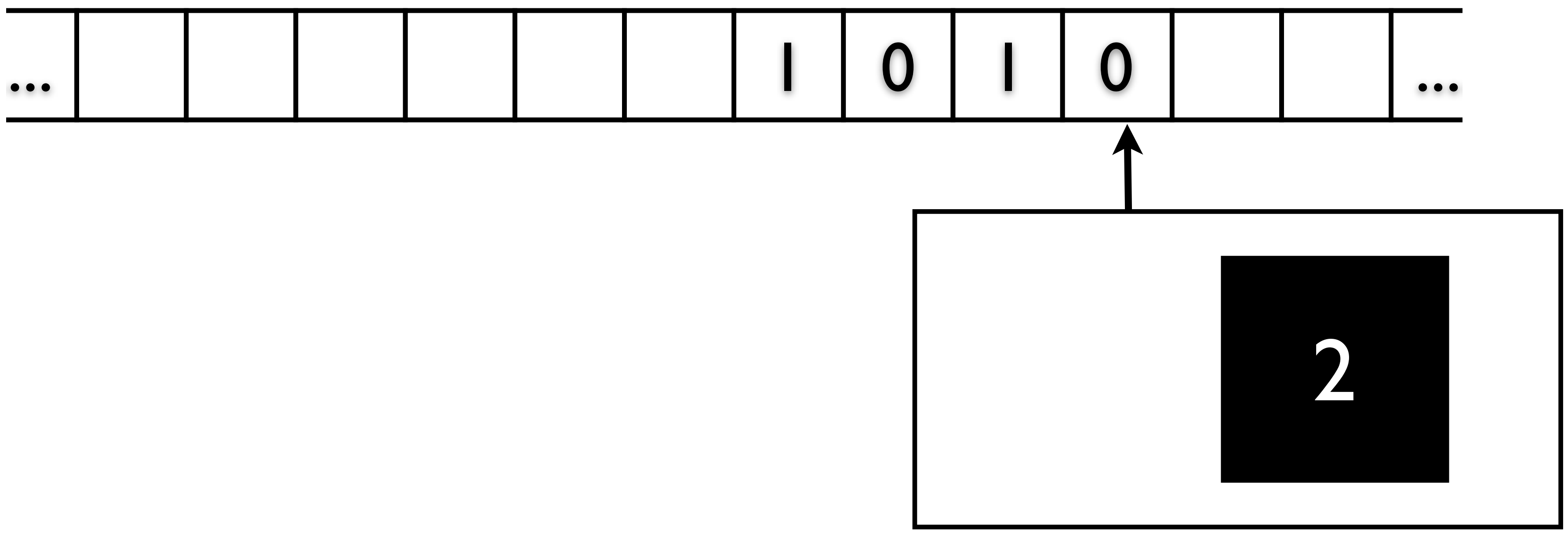
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



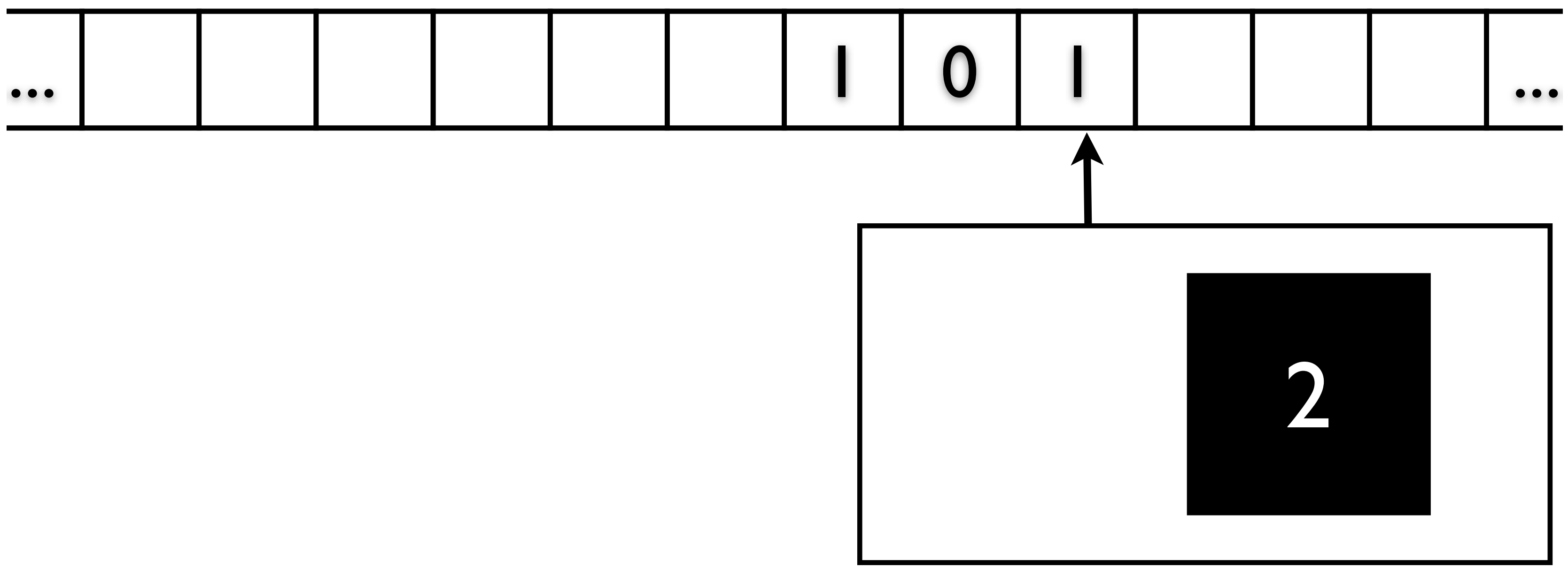
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



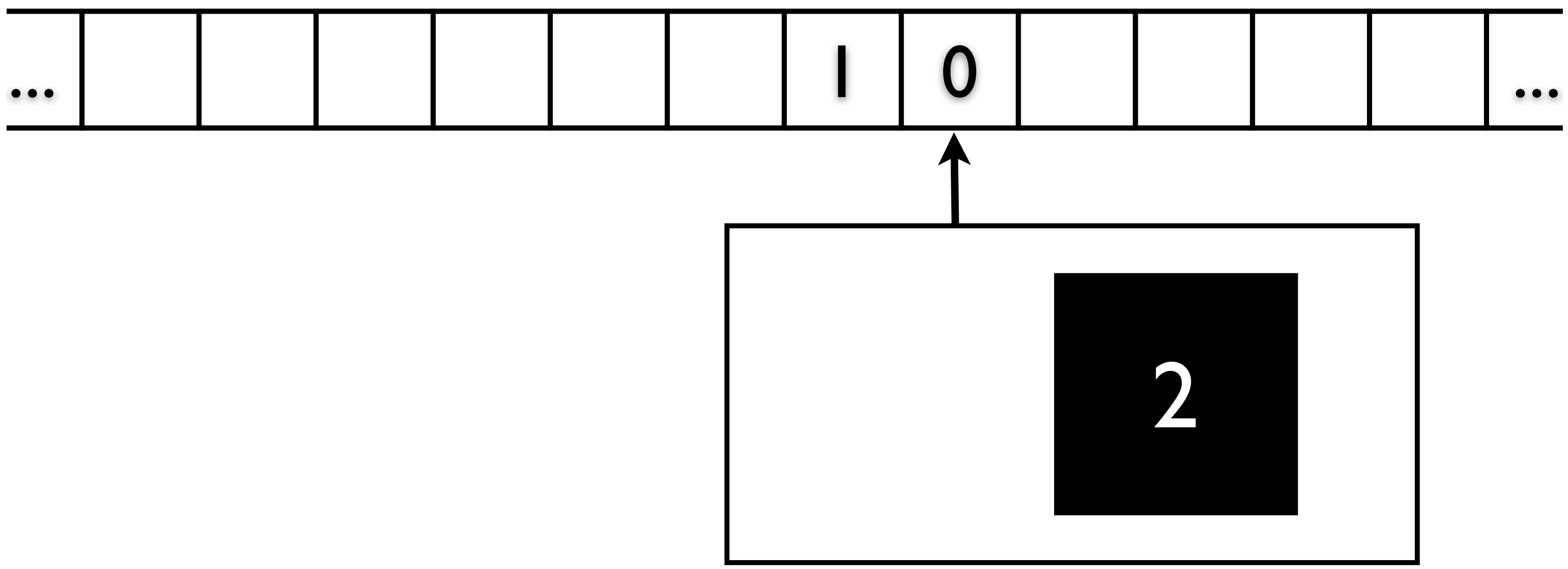
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



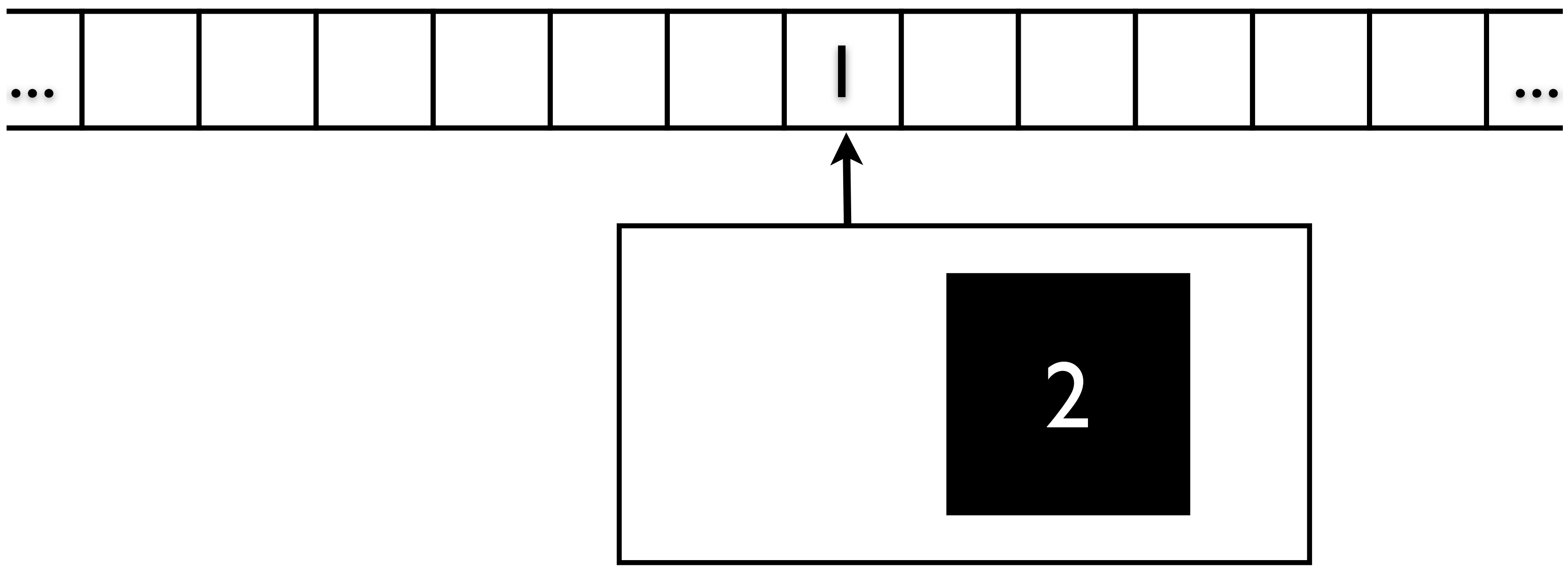
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



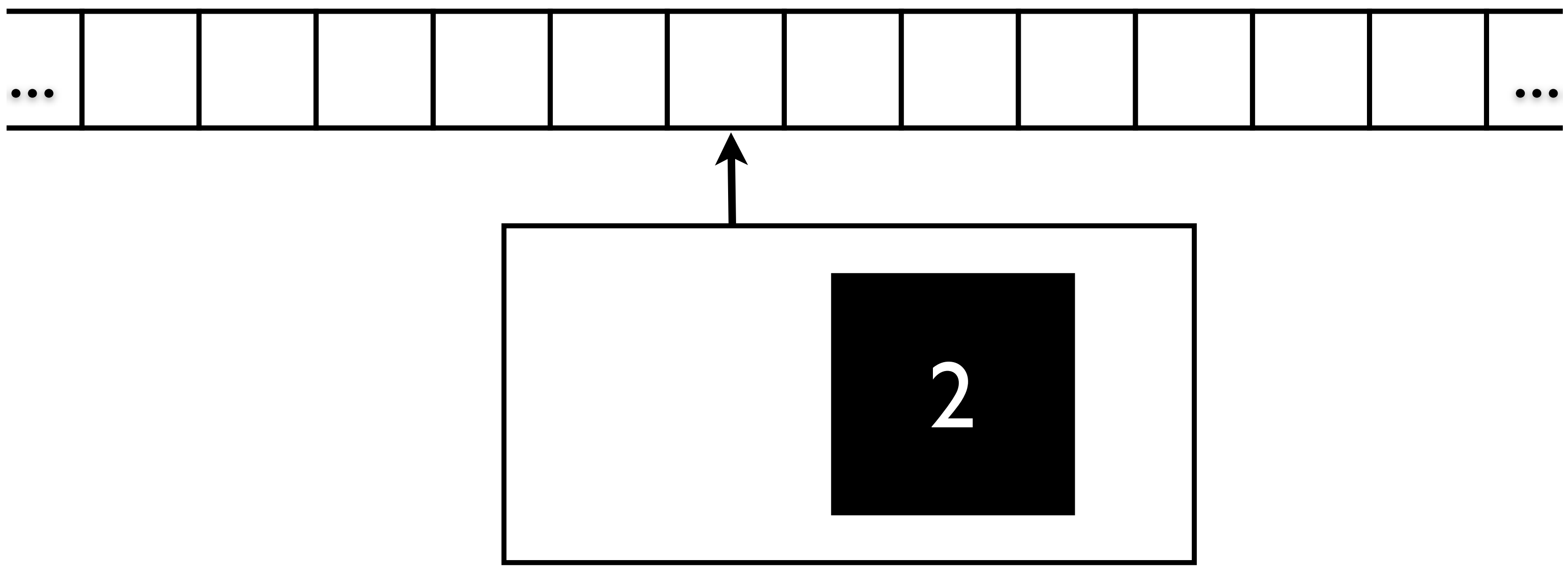
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



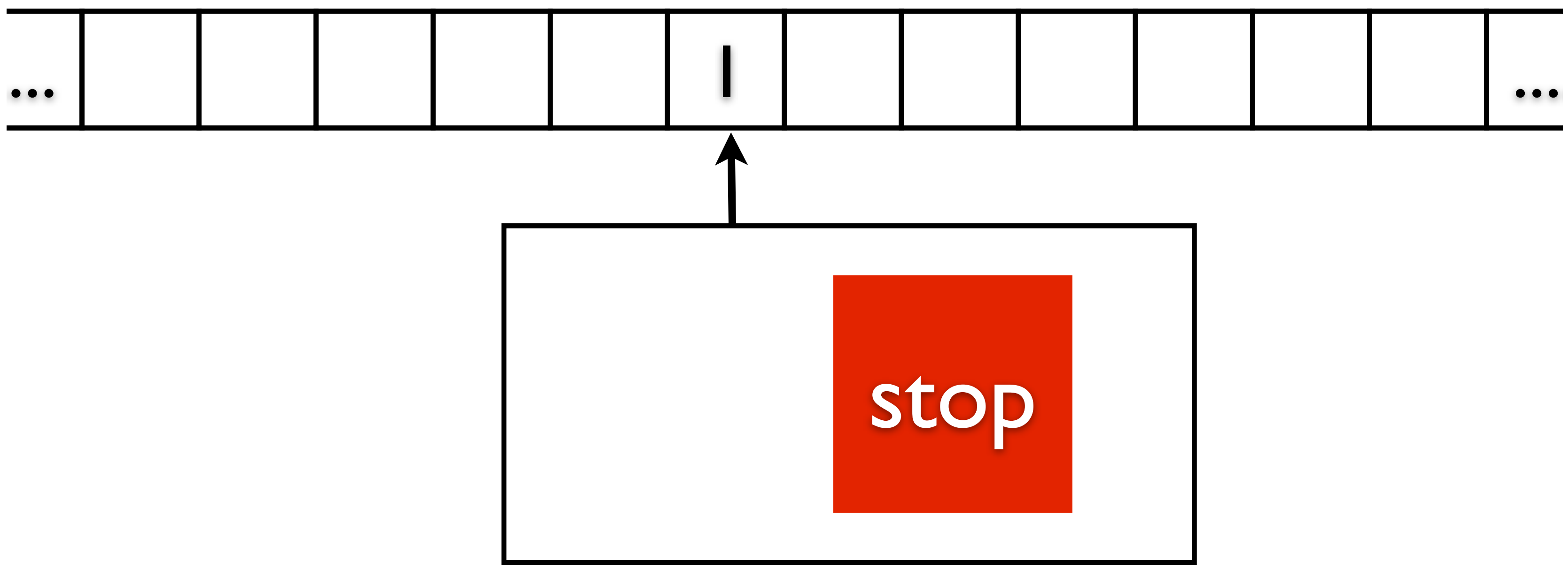
current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left



current state	current symbol	next state	next symbol	direction
3	0	3	blank	Left
3	1	3	blank	Left
3	blank	stop	0	Left
2	0	2	blank	Left
2	1	2	blank	Left
2	blank	stop	1	Left
1	1	1	1	Right
1	0	1	0	Right
1	blank	4	blank	Left
4	0	2	0	Left
4	1	3	1	Left

- Functions that can be computed in this manner are *Turing-computable*.

- Functions that can be computed in this manner are *Turing-computable*.
- Decision problems (Yes/No problems) that can answered in this manner are *Turing-decidable*.

Computation is Logic

Computation is Logic

- All computational problems can be cast into problems of the following form

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\Gamma \vdash \phi$$

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\textcircled{\Gamma} \vdash \phi$$

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\Gamma \vdash \phi$$

premises

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\Gamma \vdash \phi$$

premises

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\Gamma \vdash \phi$$

premises — conclusion

Computation is Logic

- All computational problems can be cast into problems of the following form

$$\Gamma \vdash \phi$$

premises conclusion

"Yes" or "No"

All Computation

All Computation

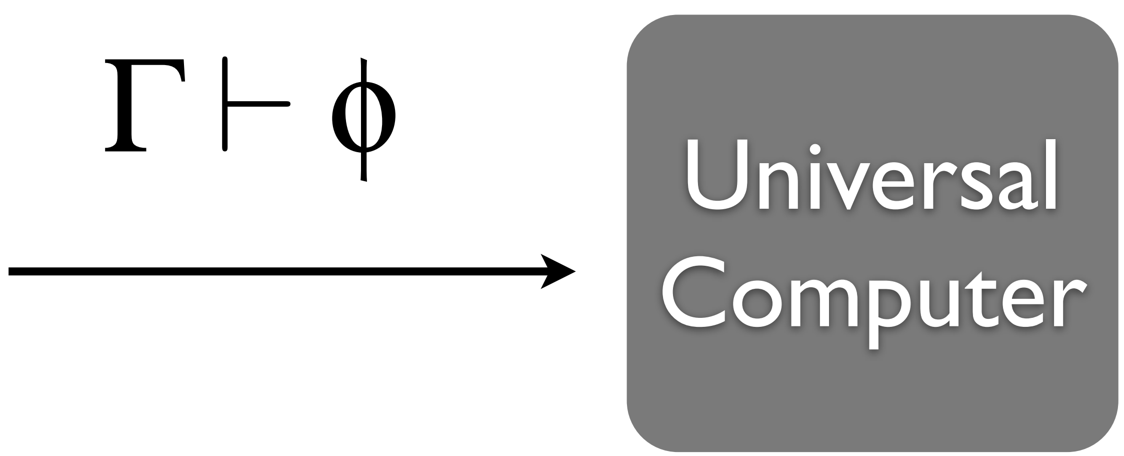
$$\Gamma \vdash \phi$$

All Computation

$\Gamma \vdash \phi$

Universal Computer

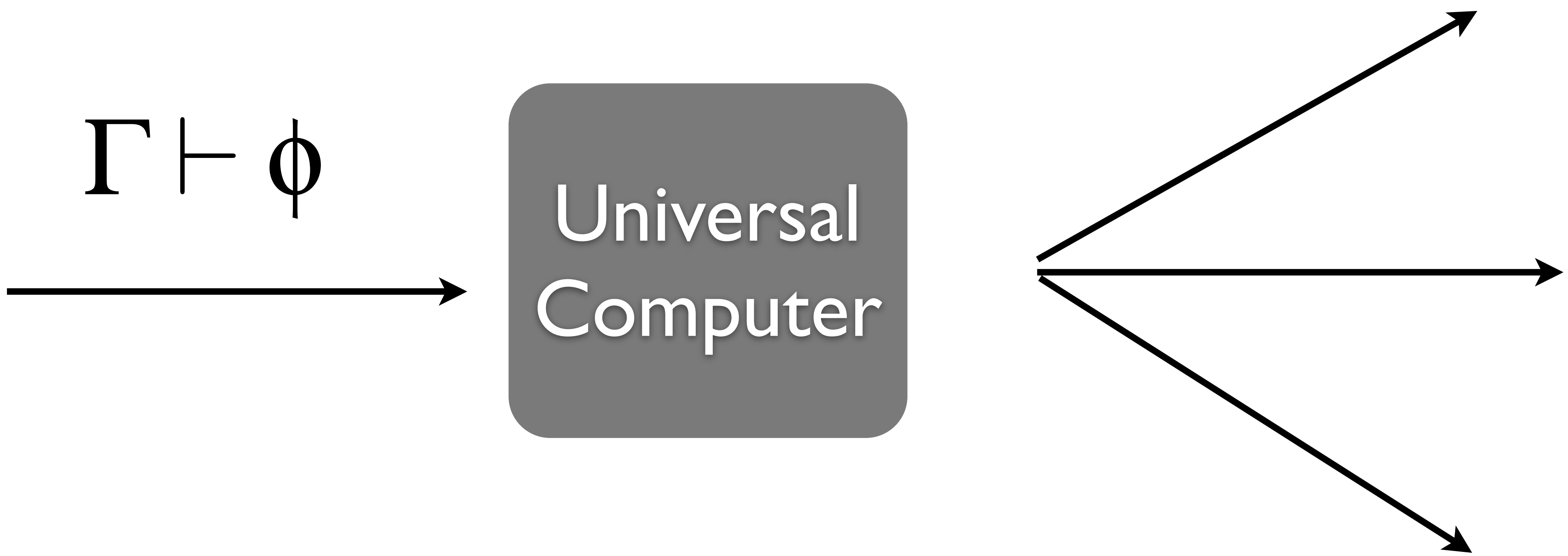
All Computation



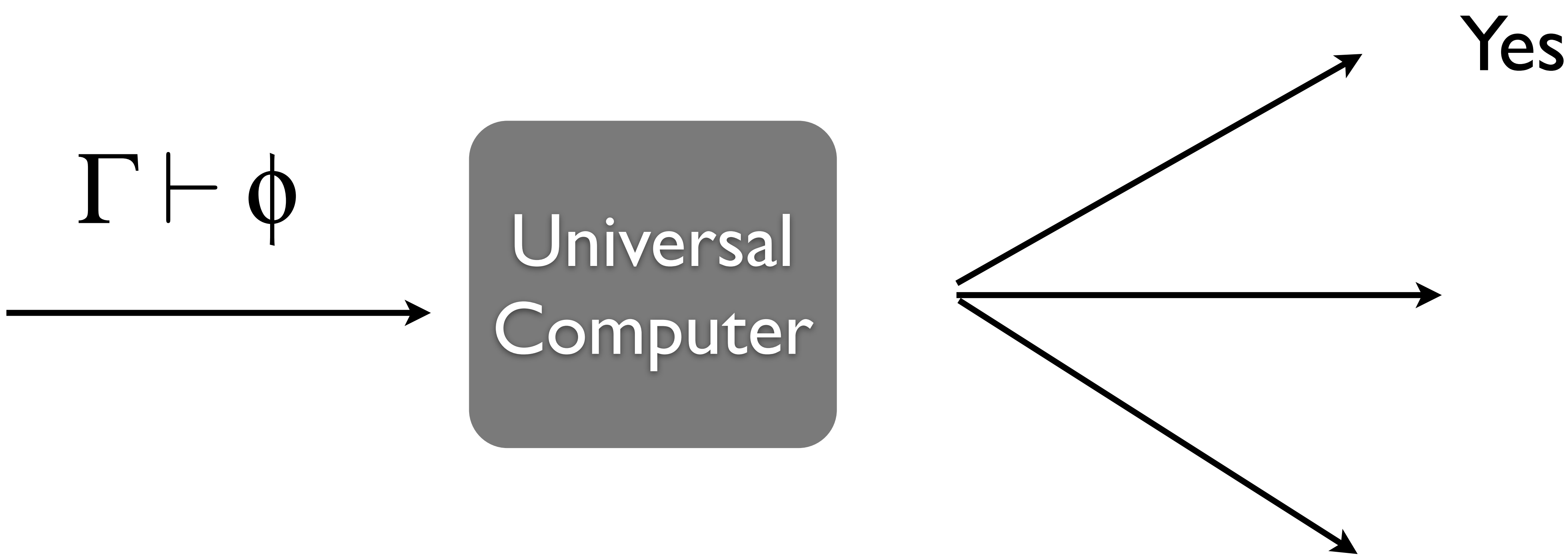
All Computation

All Computation

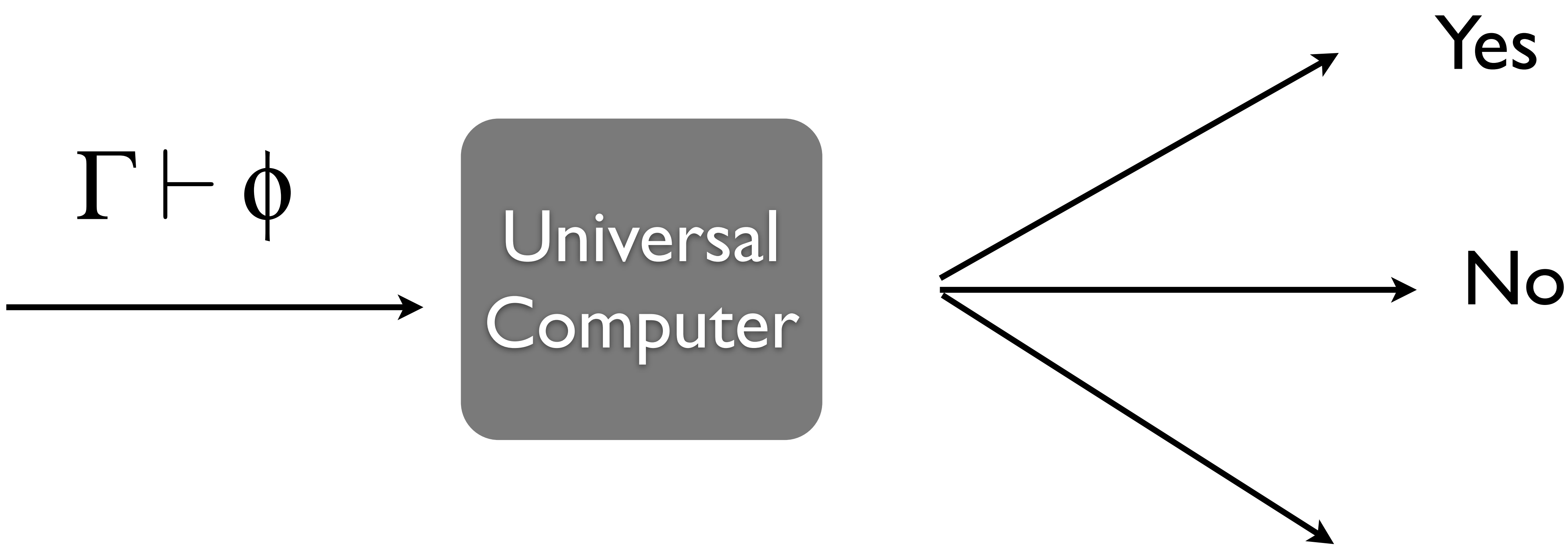
All Computation



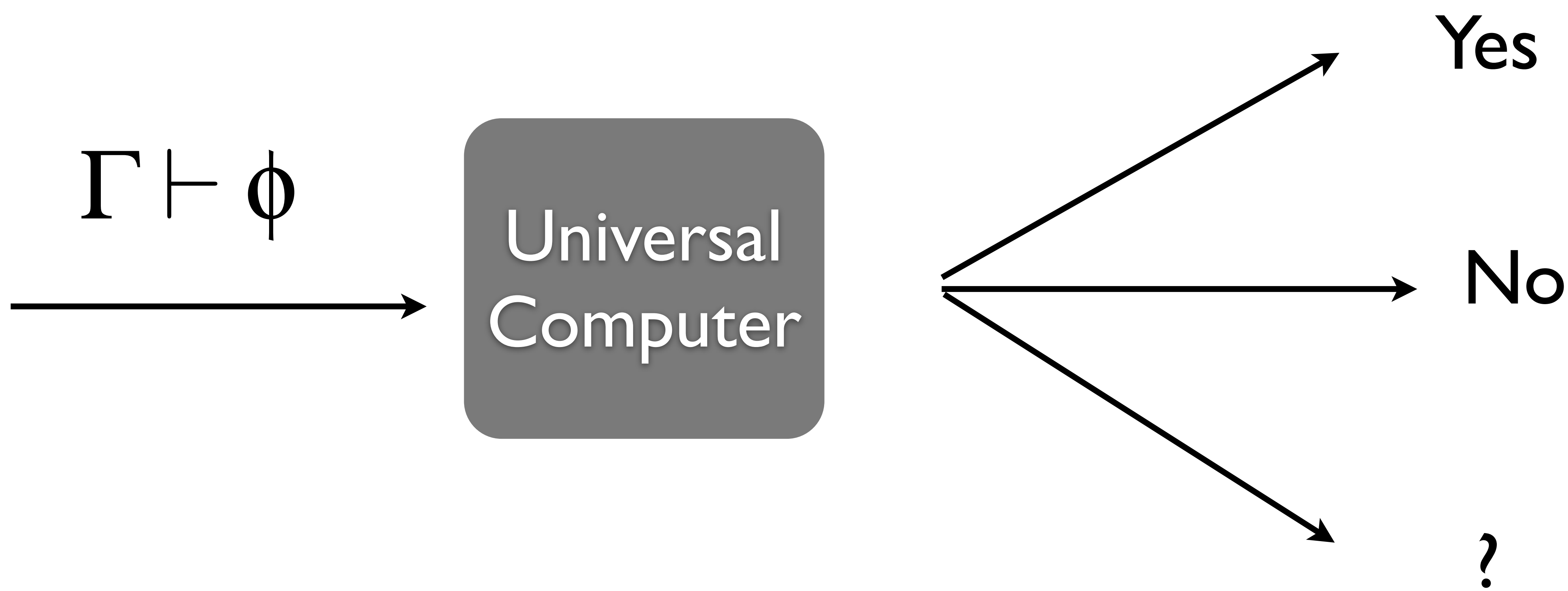
All Computation



All Computation



All Computation



Three Problem Classes

1. Decidable
2. Semi-decidable
3. Not Semi-Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes	No

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes

No

a machine

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes	No

a machine Yes

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes

No

a machine Yes

No

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes	No

a machine Yes No

Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Example: Is a given number an even number?

Yes

No

a machine Yes

No

Most problems running on the supercomputers of the world

Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes | No

Yes

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

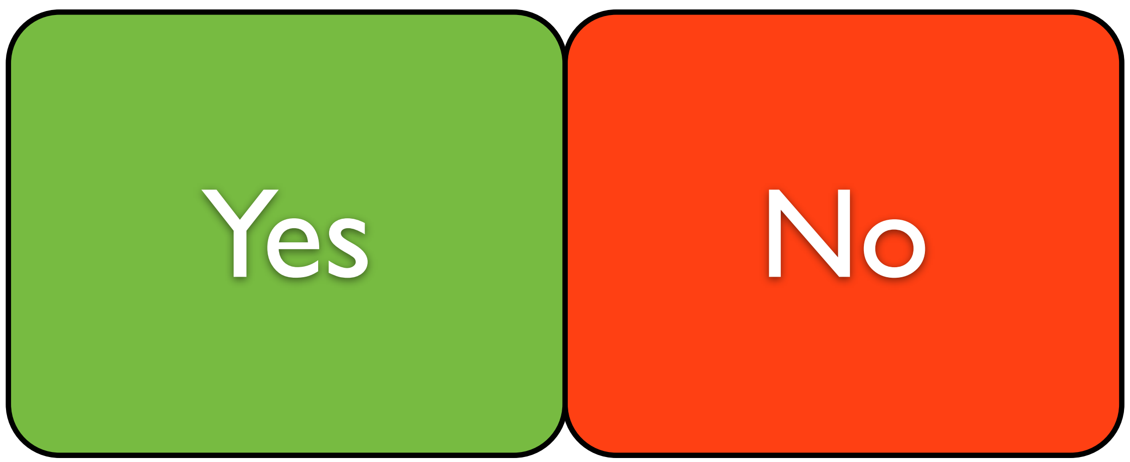
Yes	No
Yes	No/Loop

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

a machine **Yes** **No/Loop**

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$



a machine Yes No/Loop

Semi-Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

a machine **Yes** **No/Loop**

A lot of real world important problems fall into this category!

Semi-Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes

No

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

Yes/Loop

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes

No

Yes/Loop

No/Loop

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

a machine Yes/Loop No/Loop

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

Yes	No

a machine: Yes/Loop | No/Loop

Not Semi-Decidable

$$P = \{\Gamma \vdash \phi \mid \mathbf{P}\}$$

	Yes	No
a machine	Yes/Loop	No/Loop

A lot of real world important problems fall into this category!

Not Semi-Decidable

Logic Decision Problems

- **Decidable**: For every input we can have a computer answer "Yes" or "No"
- **Semi-Decidable**: There is a computer program such that if the answer is "Yes" it will say so, otherwise it may loop forever or answer "No"
- **Not Semi-Decidable**: Same as decidable but can loop even when the answer is "Yes"

Partially Concordant with My Position on *Descent of Man*

Partially Concordant with My Position on *Descent of Man*

The comparative evidence suggests, however, that nonhuman animals are unable to reason about the higher-order structural relation between these relations in a human-like fashion and are unable to perform those kinds of operations — such as recursion and deductive inference — which apply to the formal structure of a relation independently from the semantic or perceptual features of its constituents. (126)

Partially Concordant with My Position on *Descent of Man*

The comparative evidence suggests, however, that nonhuman animals are unable to reason about the higher-order structural relation between these relations in a human-like fashion and are unable to perform those kinds of operations — such as recursion and deductive inference — which apply to the formal structure of a relation independently from the semantic or perceptual features of its constituents. (126)

Partially Concordant with My Position on *Descent of Man*

The comparative evidence suggests, however, that nonhuman animals are unable to reason about the higher-order structural relation between these relations in a human-like fashion and are unable to perform those kinds of operations — such as recursion and deductive inference — which apply to the formal structure of a relation independently from the semantic or perceptual features of its constituents. (126)

Karkooking Problem …

Everyone karkooks anyone who karkooks someone.

Alvin karkooks Bill.

Can you infer that everyone karkooks Bill?

ANSWER:

JUSTIFICATION:

Larking Problem …

modus ponens, etc.!

Everyone larks anyone who larks someone.

Quantificational reasoning!

Alvin larks Bill.

Can you infer that everyone larks Bill?

Recursion!

ANSWER:

Infinitary reasoning!

JUSTIFICATION:

modus ponens, etc.!

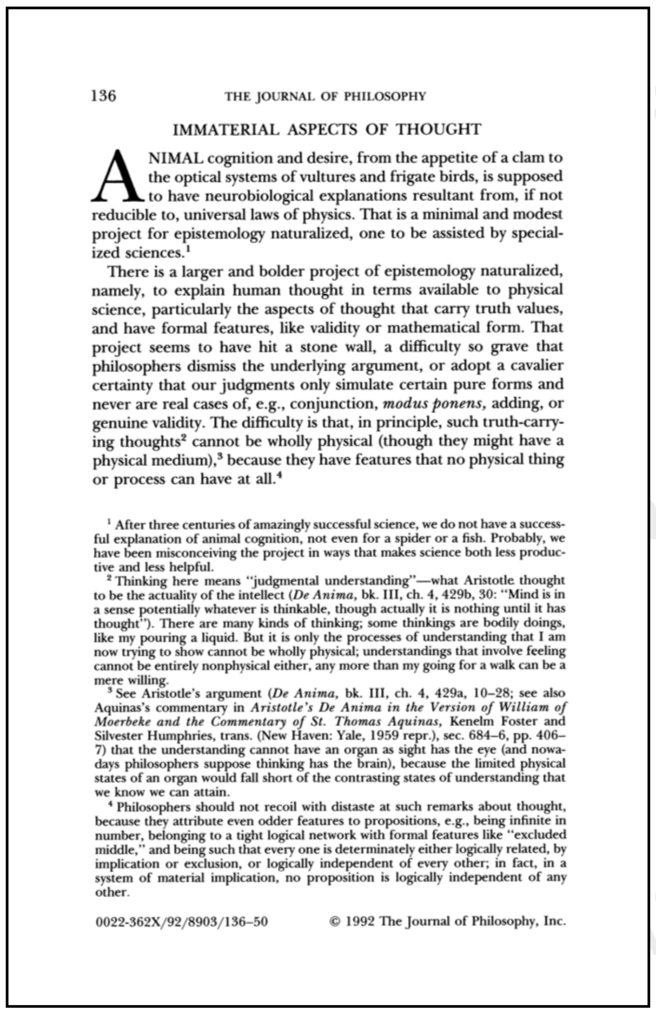
$$\frac{\phi \to \psi, \phi}{\psi}$$

Larking Problem . . .

Quantificational reasoning!

$$\frac{\forall x \phi}{\phi\frac{a}{x}}$$

arks anyone who larks someone.



IMMATERIAL ASPECTS OF THOUGHT

ANIMAL cognition and desire, from the appetite of a clam to the optical systems of vultures and frigate birds, is supposed to have neurobiological explanations resultant from, if not reducible to, universal laws of physics. That is a minimal and modest project for epistemology naturalized, one to be assisted by specialized sciences.[1]

There is a larger and bolder project of epistemology naturalized, namely, to explain human thought in terms available to physical science, particularly the aspects of thought that carry truth values, and have formal features, like validity or mathematical form. That project seems to have hit a stone wall, a difficulty so grave that philosophers dismiss the underlying argument, or adopt a cavalier certainty that our judgments only simulate certain pure forms and never are real cases of, e.g., conjunction, *modus ponens*, adding, or genuine validity. The difficulty is that, in principle, such truth-carrying thoughts[2] cannot be wholly physical (though they might have a physical medium),[3] because they have features that no physical thing or process can have at all.[4]

[1] After three centuries of amazingly successful science, we do not have a successful explanation of animal cognition, not even for a spider or a fish. Probably, we have been misconceiving the project in ways that makes science both less productive and less helpful.

[2] Thinking here means "judgmental understanding"—what Aristotle thought to be the actuality of the intellect (*De Anima*, bk. III, ch. 4, 429b, 30: "Mind is in a sense potentially whatever is thinkable, though actually it is nothing until it has thought"). There are many kinds of thinking; some thinkings are bodily doings, like my pouring a liquid. But it is only the processes of understanding that I am now trying to show cannot be wholly physical; understandings that involve feeling cannot be entirely nonphysical either, any more than my going for a walk can be a mere willing.

[3] See Aristotle's argument (*De Anima*, bk. III, ch. 4, 429a, 10–28; see also Aquinas's commentary in *Aristotle's De Anima in the Version of William of Moerbeke and the Commentary of St. Thomas Aquinas*, Kenelm Foster and Silvester Humphries, trans. (New Haven: Yale, 1959 repr.), sec. 684–6, pp. 406–7) that the understanding cannot have an organ as sight has the eye (and nowadays philosophers suppose thinking has the brain), because the limited physical states of an organ would fall short of the contrasting states of understanding that we know we can attain.

[4] Philosophers should not recoil with distaste at such remarks about thought, because they attribute even odder features to propositions, e.g., being infinite in number, belonging to a tight logical network with formal features like "excluded middle," and being such that every one is determinately either logically related, by implication or exclusion, or logically independent of every other; in fact, in a system of material implication, no proposition is logically independent of any other.

0022-362X/92/8903/136–50

James Ross: These are inference schemata that humans access, but nonhuman animals don't; and these schemata are not physical, nor reducible to anything physical.

Recursion!

Infinitary reasoning!

And now we return to the topic of “hierarchical relations” in PHP …

relation between C and A? Is A dominant to C to a greater or lesser extent than B is dominant to C? (Goodwin & Johnson-Laird 2005; Halford et al. 1998a).

In short, whereas at least some nonhuman animals clearly are able to make transitive inferences about their own relation to potential rivals to a degree that rules out purely associative learning mechanisms, the comparative evidence accumulated to date is nevertheless consistent with the hypothesis that nonhuman animals' understanding of transitive relations is punctate, egocentric, non-logical, and context-specific.

6. Hierarchical relations

Being able to process recursive operations over hierarchical relations is unarguably a key prerequisite for using a human language (Hauser et al. 2002a). And most normal human children are capable of reasoning about hierarchical class relations in a systematic and combinatorial fashion by the age of five (Andrews & Halford 2002; cf. Inhelder & Piaget 1964). Given the ubiquity and importance of hierarchical relations in human thought, the lack of any similar ability in nonhuman animals would therefore constitute a marked discontinuity between human and nonhuman minds.

6.1. Seriated cups and hierarchical reasoning

A number of comparative researchers have reinterpreted the behavior of nonhuman animals in hierarchical terms (e.g., Byrne & Russon 1998; Greenfield 1991; Matsuzawa 1996). In each of these cases, however, there is no evidence that the nonhuman animals themselves cognized the task in hierarchical terms or employed hierarchically structured mental representations to do so. The most widely cited case of hierarchical reasoning among nonhuman animals, for example, has come from experiments involving seriated cups. It has been claimed that "subassembly" (i.e., combining two or more cups as a subunit with one or more other cups) requires the subject to represent these nested relations in a combinatorial and "reversible" fashion (Greenfield 1991; Westergaard & Suomi 1994). Indeed, Greenfield (1991) argued that children's ability to nest cups develops in parallel with their ability to employ hierarchical phonological and grammatical constructions, and therefore, that the ability of nonhuman primates to seriate cups is the precursor to comprehending hierarchical grammars (see Matsuzawa 1996 for claims of a similar "isomorphism" between tool and symbol use).

But is it actually necessary to cognize hierarchically structured relations in order to assemble nested cups? To date, Johnson-Pynn, Fragaszy, and colleagues have provided the most convincing evidence that a nonhuman animal can use subassembly to assemble seriated cups (Fragaszy et al. 2002; Johnson-Pynn & Fragaszy 2001; Johnson-Pynn et al. 1999). Yet, Johnson-Pynn and Fragaszy themselves dispute the claim that this behavior requires hierarchical relational operations of the kind suggested by Greenfield (1991).

Fragaszy et al. (2002), for example, presented seriated cups to adult capuchin monkeys, chimpanzees, and 11-, 16-, and 21-month-old children. Children of all three ages created five-cup sets less consistently than the nonhuman subjects did, and they were rarely able to place a sixth cup into a seriated set. Bizarrely, at least for a purely relational interpretation of the results, monkeys were more successful than either apes or human children on the more challenging six-cup trials, yet were also the most inefficient (in terms of number of moves) of the three populations.

Fragaszy et al.'s (2002) explanation for these anomalous results is quite sensible (see also Fragaszy & Cummins-Sebree 2005): They hypothesize that the seriation task does not, in fact, require the subject to reason about combinatorial, hierarchical relations per se, but depends more simply on situated, embodied sensory-motor skills that are experientially, rather than conceptually, driven. Apes and monkeys do better than children because they are more physically adept than 11- to 21-month-old children are – not because they have a more sophisticated representation of the combinatorial and hierarchical relations involved. Although subassembly may be a more physically "complex" strategy than other methods of seriation, it does not necessarily require the subject to cognize the spatial-physical relations involved as hierarchical; and therefore there is no reason to claim an isomorphism between the embodied manipulation of nested cups and the cognitive manipulation of symbolic-relational representations (cf. Greenfield 1991; Matsuzawa 1996).

6.2. Hierarchical relations in the wild

The strongest evidence to date in support of the claim that nonhuman animals can reason about hierarchically structured relations in the social domain comes from Bergman et al.'s (2003) study of free-ranging baboons. Bergman et al. designed an elegant playback experiment in which female baboons heard a sequence of recorded calls mimicking a fight between two other females. Mock agonistic confrontations were created by playing the "threat-grunt" of one individual followed by the subordinate screams of another. On separate days, the same subject heard one of three different call sequences: (1) an anomalous sequence mimicking a rank reversal between members of the same matrilineal family (i.e., sisters, mothers, daughters, or nieces); (2) an anomalous sequence mimicking a between-family rank reversal (i.e., between members of two different matrilineal families in which one of the families is dominant to the other); or (3) a control sequence replicating an existing dominant-subordinate relationship (i.e., no rank reversal) using between-family or within-family dyads. As predicted, there was a significant difference in the focal subjects' responses to the three different kinds of call sequences. Subjects looked longest at between-family rank reversals. There was no significant difference between within-family reversals and no-reversal control sequences. According to Bergman et al., the reason the baboons responded more strongly to between-family rank reversals than within-family sequences is because the baboons recognized that the former imply a superordinate reorganization of matrilineal subgroups. Bergman et al. (2003, p. 1236) conclude: "Our results suggest that baboons organize their companions into a hierarchical, rule-governed structure based simultaneously on kinship and rank" (see also Seyfarth et al. 2005).

Being able to process recursive operations over hierarchi-cal relations is unarguably a key prerequisite for using a human language (Hauser et al. 2002a). And most normal human children are capable of reasoning about hierarchical class relations in a systematic and combinatorial fashion by the age of five (Andrews & Halford 2002; cf. Inhelder & Piaget 1964). Given the ubiquity and importance of hierarchical relations in human thought, the lack of any similar ability in nonhuman animals would therefore constitute a marked discontinuity between human and nonhuman minds.

6.1. Seriated cups and hierarchical reasoning

A number of comparative researchers have reinterpreted the behavior of nonhuman animals in hierarchical terms (e.g., Byrne & Russon 1998; Greenfield 1991; Matsuzawa 1996). In each of these cases, however, there is no evidence that the nonhuman animals themselves cognized the task in hierarchical terms or employed hierarchically structured mental representations to do so. The most widely cited case of hierarchical reasoning among nonhuman animals, for example, has come from experiments involving seriated cups. It has been claimed that “subassembly” (i.e., combining two or more cups as a subunit with one or more other cups) requires the subject to represent these nested relations in a combinatorial and “reversible” fashion (Greenfield 1991; Westergaard & Suomi 1994). Indeed, Greenfield (1991) argued that children’s ability to nest cups develops in parallel with their ability to employ hierarchical phonological and grammatical constructions, and therefore, that the ability of nonhuman primates to seriate cups is the precursor to comprehending hierarchical grammars (see Matsuzawa

monkeys do better than
physically adept than
are – not because they
resentation of the combi
involved. Although subas
“complex” strategy than
not necessarily require t
physical relations involv
there is no reason to cla
embodied manipulation
manipulation of sym
(cf. Greenfield 1991; Ma

6.2. Hierarchical relatio

The strongest evidence t
nonhuman animals can
tured relations in th
Bergman et al.’s (2003)
Bergman et al. designed
in which female baboon
calls mimicking a fight b
agonistic confrontations
“threat-grunt” of one in
nate screams of anothe
subject heard one of th
an anomalous sequen
between members of t
sisters, mothers, daught
sequence mimicking a b
between members of tw
which one of the famil
(3) a control sequence
subordinate relationshi

? Is A dominant to C to a greater is dominant to C? (Goodwin & ord et al. 1998a).

least some nonhuman animals transitive inferences about their rivals to a degree that rules out g mechanisms, the comparative date is nevertheless consistent at nonhuman animals' under-lations is punctate, egocentric, specific.

ns

ursive operations over hierarchi-y a key prerequisite for using a et al. 2002a). And most normal ble of reasoning about hierarchi-ematic and combinatorial fashion s & Halford 2002; cf. Inhelder & biquity and importance of hier-man thought, the lack of any an animals would therefore con-uity between human and nonhu-

ierarchical reasoning

e researchers have reinterpreted an animals in hierarchical terms 98; Greenfield 1991; Matsuzawa

ages created five-cup sets less consistently than the nonhuman subjects did, and they were rarely able to place a sixth cup into a seriated set. Bizarrely, at least for a purely relational interpretation of the results, monkeys were more successful than either apes or human children on the more challenging six-cup trials, yet were also the most inefficient (in terms of number of moves) of the three populations.

Fragaszy et al.'s (2002) explanation for these anomalous results is quite sensible (see also Fragaszy & Cummins-Sebree 2005): They hypothesize that the seriation task does not, in fact, require the subject to reason about combinatorial, hierarchical relations per se, but depends more simply on situated, embodied sensory-motor skills that are experientially, rather than conceptually, driven. Apes and monkeys do better than children because they are more physically adept than 11- to 21-month-old children are – not because they have a more sophisticated representation of the combinatorial and hierarchical relations involved. Although subassembly may be a more physically "complex" strategy than other methods of seriation, it does not necessarily require the subject to cognize the spatial-physical relations involved as hierarchical; and therefore there is no reason to claim an isomorphism between the embodied manipulation of nested cups and the cognitive manipulation of symbolic-relational representations (cf. Greenfield 1991; Matsuzawa 1996).

6.2. Hierarchical relations in the wild

The strongest evidence to date in support of the claim that nonhuman animals can reason about hierarchically struc-

In our view, the evidence reported by Bergman et al. (2003) does not support this conclusion. Even if baboons do make a categorical distinction between kin and non-kin dyads based on interaction history, familiarity, spatial proximity, phenotypic cues, or some other observable regularity (see Silk 2002a for a review of the possibilities), this does not necessarily mean that they represent the entire matrilineal social structure as an integrated relational schema in which non-kin relations are logically superordinate to between-kin relations. As Bergman et al. (2003) themselves point out, between-family rank reversals are much more disruptive to baboon social life than within-family rank reversals. Therefore, Bergman et al.'s (2003) results are consistent with the hypothesis that female baboons have learned that rank reversals among non-kin are more salient (i.e., associated with greater social turmoil and personal risk) than are within-kin rank reversals occurring in someone else's family (notably, Bergman et al. did not test rank reversals within the focal subject's own family). While baboons clearly recognize particular conspecifics' vocalizations and represent dominance and kin relations in a combinatorial manner, there is nothing in Bergman et al.'s data that remotely suggests a higher-order, hierarchical relation among these representations.

Once again, there is not simply an absence of evidence; there is evidence of an absence. Bergman et al. (2003) note that the subjects' responses to apparent rank reversals were unrelated to the rank distance separating the two signalers: that is, subjects paid as much attention to mock rank reversals involving closely ranked opponents as those involving more distantly ranked opponents. Bergman et al. use this fact to rebut the hypothesis that the baboons were responding more strongly to between-family rank reversals simply because the individuals involved had more disparate ranks. However, the data cut both ways: If the baboons did cognize the relation between female conspecifics as an integrated matrilineal dominance hierarchy, *ceteris paribus*, they should have been more surprised at a rank reversal between a very low ranking and a very high ranking individual than by a rank reversal between two individuals of adjacent ranks. Ironically, Bergman et al.'s results provide some of the strongest evidence to date that female baboons do not, in fact, cognize the structure of their conspecifics' matrilineal social relationships in a systematic or hierarchical fashion.

7. Causal relations

There is ample evidence that traditional associationist models are inadequate to account for nonhuman causal cognition; but the available comparative evidence also suggests that there is a critical and qualitative difference between the ways that human and nonhuman animals reason about causal relations (see Penn & Povinelli 2007a for a more extensive review and discussion). Humans explicitly reason in terms of unobservable and/or hidden causes (Hagmayer & Waldmann 2004; Kushnir et al. 2005; Saxe et al. 2005), distinguish between "genuine" and "spurious" causes (Lien & Cheng 2000), reason diagnostically from effects to their possible causes (Waldmann & Holyoak 1992), and plan their own interventions in a quasi-experimental fashion to elucidate ambiguous causal relations (Hagmayer et al. 2007). Numerous researchers have argued that normal humans – not just scientists or philosophers – form "intuitive theories" or "mental models" about the unobservable principles and causal forces that shape relations in a specific domain (e.g., Carey 1985; Gopnik & Meltzoff 1997; Keil 1989; Murphy & Medin 1985). These tacit systems of higher-order relations at various levels of generality modulate how human subjects judge and discover novel relations within those domains by a process akin to analogical inference (Goldvarg & Johnson-Laird 2001; Lee & Holyoak 2007; Lien & Cheng 2000; Tenenbaum et al. 2007). In short, the ability to reason about higher-order, analogical relations in a systematic and productive fashion appears to be an integral aspect of human causal cognition.

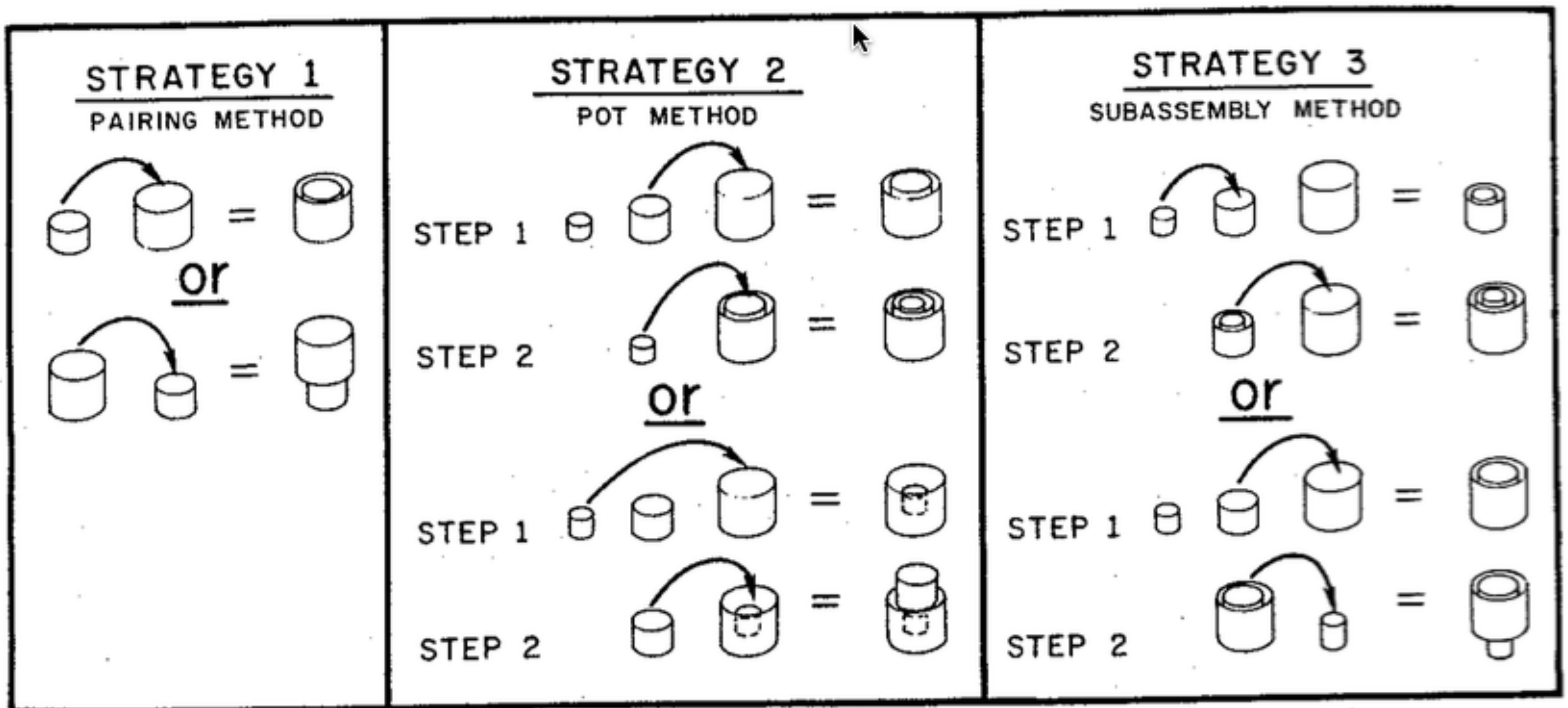
In stark contrast to the human case, there is no compelling evidence that nonhuman animals form tacit theories about the unobservable causal mechanisms at work in the world, seek out explanations for anomalous causal relations, reason diagnostically about unobserved causes, or distinguish between genuine and spurious causal relations on the basis of their prior knowledge of abstract causal mechanisms.[2] Indeed, there is consistent evidence of an absence across a variety of protocols (see, e.g., Penn & Povinelli 2007a; Povinelli 2000; Povinelli & Dunphy-Lelii 2001; Visalberghi & Tomasello 1998).

A variety of nonhuman animal species – and certainly not primates alone (Emery & Clayton 2004b) – are able to construct and use tools in a flexible and adaptive fashion. But a series of seminal experiments, initiated by Visalberghi and colleagues (see Visalberghi & Limongelli 1996 for a review), provides a particularly compelling example of how nonhuman animals' remarkable use of tools nevertheless belies a fundamental discontinuity with our human understanding of causal relations.

Visalberghi and Limongelli (1994) tested capuchin monkeys' ability to retrieve a piece of food placed inside a transparent tube using a straight stick. In the middle of the tube, there was a highly visible hole with a small transparent cup attached. If the subject pushed the food over the hole, the food fell into the cup and was inaccessible ("trap-down" condition). Visalberghi and Limongelli (1994) tested four capuchin monkeys to see whether they would understand that they needed to push the food out the end of the tube away from the hole. After about 90 trials, only one out of the four capuchin monkeys learned to push the food away from the hole, and even this one learned the correct behavior through trial and error. Worse, once the experimenters rotated the tube so that the trap hole was now facing up and causally irrelevant ("trap-up" condition), the one successful capuchin still persisted in treating the hole as if it needed to be avoided – making it obvious that even this subject misunderstood the causal relation between the trap hole and the retrieval of the reward.

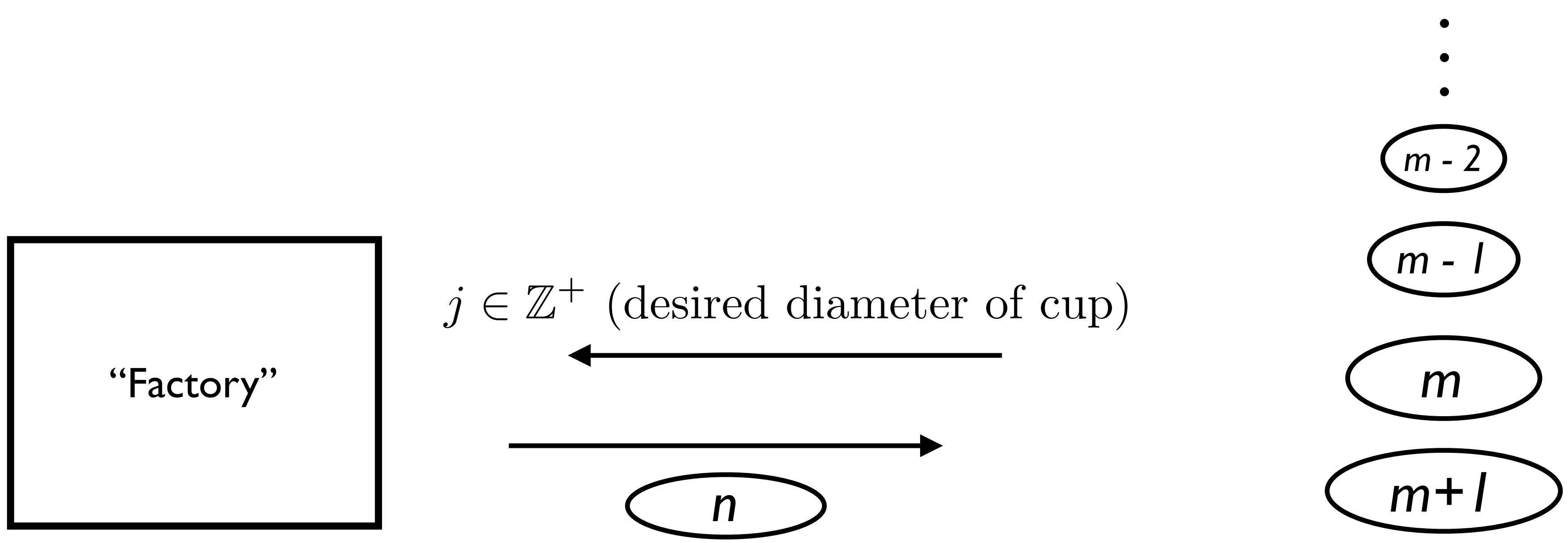
Povinelli (2000) and colleagues subsequently replicated Visalberghi's trap-tube protocol with seven chimpanzees. Povinelli performed the experiments once when the chimpanzees were juveniles (5 to 6 years old) and again when they were young adults (10 years old). Three out of the seven chimps learned to solve the trap-down version of the task as adults, with one chimp, Megan, learning to

Context: Assembly (Seriated Cups)



Selmer's Seriated Cup Challenge, Part 1

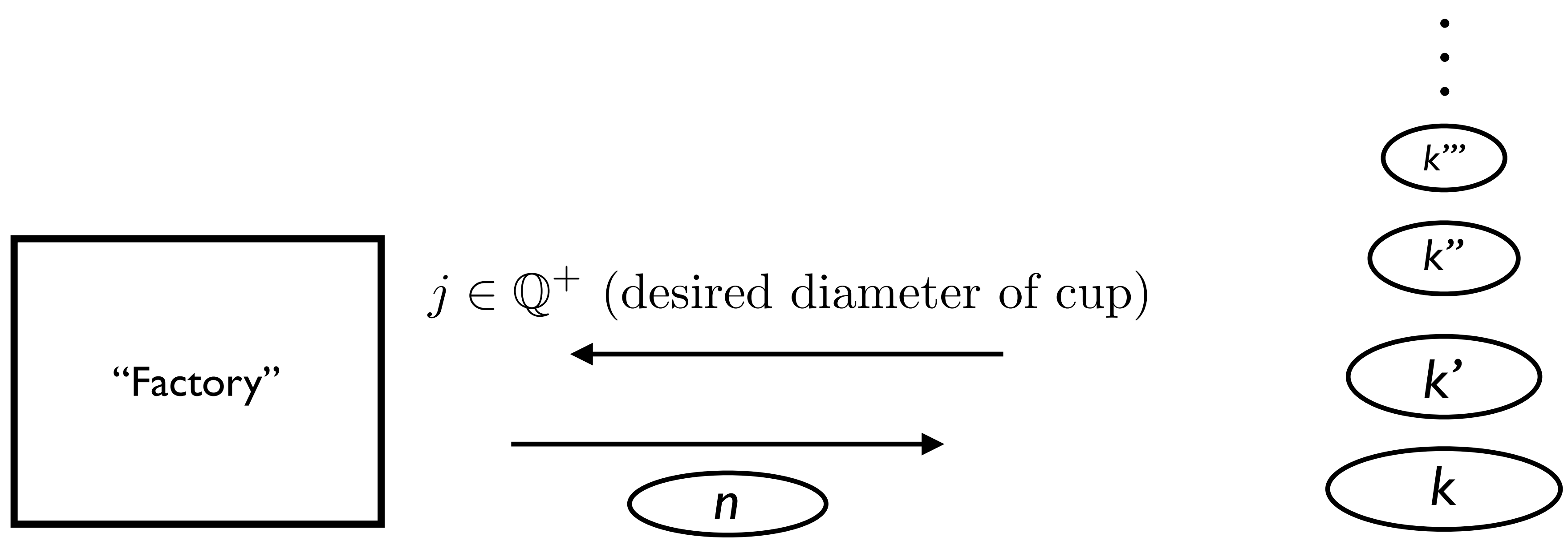
Suppose you have at your disposal a "factory" that, upon hearing you announce a number *j*, can quickly output a cup having a diameter of precisely *j* units. Can you insert a new cup between two of the seriated cups in the tower shown here? — where the *j* you send in *must* be a positive integer, *m* is likewise a positive integer, and every cup in every tower must be more in diameter than the one immediately above it, and less in diameter than the one immediately below it?** Prove that your answer is correct.



**E.g., if *m* = 3, the tower in that case will have a base cup 4 units in diameter, immediately above that a cup 3 units in diameter, then a cup 2 units in diameter, and then finally a top cup of 1 unit in diameter.

Selmer’s Seriated Cup Challenge, Part II

Suppose you have at your disposal a “factory” that, upon hearing you announce a number *j*, can quickly output a cup having a diameter of precisely *j* units. Can you insert a new cup between two of the seriated cups in the tower shown here? — where the *j* you send in *must* be a positive rational number; *k, k’, k”, k’”* … are likewise positive rational numbers, and every cup in every tower must be more in diameter than the one immediately above it, and less in diameter than the one immediately below it?** Prove that your answer is correct.



**E.g., if *k* = $\frac{1}{2}$, the tower in that case will have a base cup $\frac{1}{2}$ units in diameter, immediately above that there could be a cup $\frac{1}{3}$ units in diameter, then perhaps a cup $\frac{1}{4}$ units in diameter, and then perhaps finally a top cup of $\frac{1}{32}$ units in diameter.

Humans

Animals

Humans	Humans can discover answers and corresponding proofs at the level (minimally) of elementary *infinitary* number and set theory.
Animals	

Humans	Humans can discover answers and corresponding proofs at the level (minimally) of elementary *infinitary* number and set theory.
Animals	Nonhuman animals can't do anything of the sort.

Humans

Humans can discover answers and corresponding proofs at the level (minimally) of elementary *infinitary* number and set theory.

Animals

Nonhuman animals can't do anything of the sort.

Some elements of some formalized human-animal behavior have zero overlap with any elements of some formalized animal behavior!

Humans

Humans can discover answers and corresponding proofs at the level (minimally) of elementary *infinitary* number and set theory.

Animals

Nonhuman animals can't do anything of the sort.

Some elements of some formalized human-animal behavior have zero overlap with any elements of some formalized animal behavior!

Humans Humans can discover answers and corresponding proofs at the level (minimally) of elementary *infinitary* number and set theory.

Animals Nonhuman animals can't do anything of the sort.

Some elements of some formalized human-animal behavior have zero overlap with any elements of some formalized animal behavior!

But can we *prove* discontinuity?

Formalization of Cognitive Continuity/Discon., to Settle the Darwin's-Mistake Debate

Selmer Bringsjord • Atriya Sen • Naveen Sundar G. • Christina Elmore • Matt Peveler
Rensselaer AI & Reasoning Lab • Dept of Cognitive Science • Dept of Computer Science
Rensselaer Polytechnic Institute (RPI) • Troy NY 12180 USA • `Selmer.Bringsjordm@gmail.com`

Rensselaer AI and Reasoning Lab

Introduction

Darwin's (1859) *Origin* doesn't discuss the evolution of the human mind. He saved treatment of this topic for the subsequent *Descent of Man* (1997), in which he advanced two claims:

- **C1** If the cognitive powers of nonhuman animals are discontinuous with those possessed by humans, then the human mind isnt the product of evolution by mutation and natural selection.
- **C2** The cognitive powers of nonhuman animals, including specifically reasoning powers, are continuous with those enjoyed by humans; continuity is established.

Penn, Holyoak, and Povinelli (2008) have written "Darwin's Mistake," in which they purport to refute C2 by establishing discontinuity (they don't in this paper affirm C1). Many vehemently disagree with PHP (witness the commentaries on PHP's target *BBS* paper), and the debate remains intense, and unresolved. Yet, (1) the hitherto informal concept of continuity can be formalized, and (2) that formalization, applied to the debate, settles it. We provide the formalization (and corresponding simulations), and with it settle the debate (in favor of PHP). Our work falls under AI and computational cognitive modeling of the logicist variety, a fact we here simply report without defense (for explanation and defense e.g. see Bringsjord 2008*b*, Bringsjord 2008*a*)

Logico-mathematical Ingredients

A collection of formal ingredients are necessary to adjudicate the debate over C2. In general, we need the following quartet:

Cognitive Calculi A cognitive calculus $\mathscr{C}$ can be viewed as a pair $\langle \mathcal{L}, \mathcal{I} \rangle$ where $\mathcal{L}$ is a formal language (based therefore on an alphabet and a formal grammar) able to represent mental states and $\mathcal{I}$ is a set of inference schemata extending to at least quantified modal third-order logic. Conveniently, cognitive calculi fall into an infinite order $\mathscr{C}_1 < \mathscr{C}_2 < \mathscr{C}_3 \ldots$ of increasing power.

Problem Classes/Problems We need to have on hand a precise definition of the relevant problems p that fall into their problem classes PROB. Herein, we mention only a pair of problems: p_1 is the language-recognition problem of deciding whether a simple song coded as a string u built from the alphabet $\{a, b\}$ is of the specific form $a^n b^n$; p_2 is the extended seriated cup challenge of obtaining a plan that, when executed, secures a goal configuration g of cups, where g is allowed to be an arbitrary first-order formula (e.g. "Every small cup is inside at least three cups larger than itself").[1] See Fig. 1.

Solvability/Unsolvability Here we simply appropriate these concepts from the theory of un/computability, according to which problems can be classified e.g. as Turing-solvable/unsolvable.

Production of a New Cog. Calc. from a Prior One We need a set of processes by which, from a cognitive calculus $\mathscr{C}_1$ a new $\mathscr{C}_2$ is produced (we write $\mathscr{C}_1 \longrightarrow \mathscr{C}_2$). In many ways the history of computational logic for AI (and, to a degree, cognitive science) has consisted in humans, faced with the fact that a given logical system is inadequate for solving a given problem, inventing a new logical system that gets the job done (e.g. see Glymour 1992).

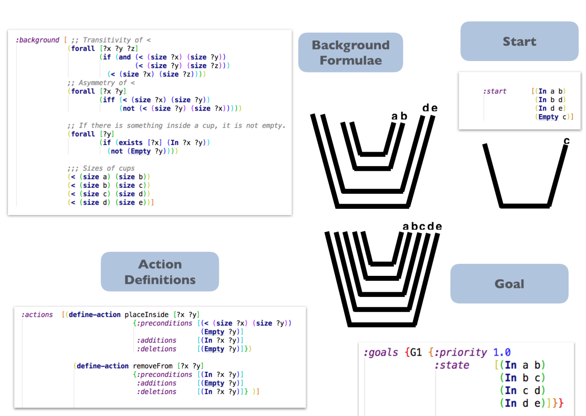


Figure 1: Extended (requires full first-order logic; note quantification) Seriated Cup Challenge Expressed in Spectra

Technology Ingredients from Logicist AI/CogSci

One particular cognitive calculus that serves our needs nicely in modeling problems in connection with the agents that face them is the **deontic cognitive event calculus** ($\mathcal{DCEC}^*$) (**?**). $\mathcal{DCEC}^*$ is a multi-sorted quantified modal logic that includes operators for what an agent might Believe, Know, Desire, Perceive, or Say (as well as operators for what the agent has an Obligation or Intention to do). From the AI-technology side, we use Spectra (Govindarajulu, Naveen Sundar 2017), a new, unprecedentedly expressive state-of-the-art planner which utilizes the automated reasoner ShadowProver (Govindarajulu, Naveen Sundar 2016) as its core to discover a plan from the initial state, the goal, and the possible ways a state may change as actions are performed; see Fig. 1.

[1] Former problem class given in (Gentner, Fenn, Marrgoliash & Nusbaum n.d.). Latter problem class is an extension of a simple one discussed by PHP in §6.1 of their paper.
[2] We use 'chimps' to refer to extant species under the genus Pan.
[3] http://kryten.mm.rpi.edu/sb_lccm_ab-toc_031607.pdf

Defining Discontinuity

The core idea behind the concept of discontinuity we employ is straightforward: one agent, $\mathfrak{a}_1$, is discontinuously above a second agent, $\mathfrak{a}_2$, just in case there are at least two problems p_1 and p_2 that irremediably (relative to $\mathfrak{a}_1$) separate them. More formally:

> $\mathfrak{a}_1$ is discontinuously above $\mathfrak{a}_2$ iff
>
> $\exists\, \mathscr{C}, \mathscr{C}', p, \text{PROB}, p', \text{PROB}'$:
>
> (i)
> $Solves(\mathfrak{a}_1, p \in \text{PROB}, \mathscr{C}) \wedge Solves(\mathfrak{a}_2, p' \in \text{PROB}', \mathscr{C}') \wedge$
> $Solves(\mathfrak{a}_2, p \in \text{PROB}, \mathscr{C}) \wedge \neg Solves(\mathfrak{a}_1, p' \in \text{PROB}', \mathscr{C}') \wedge$
>
> (ii) $\mathscr{C} < \mathscr{C}'$
>
> (iii) $\neg \Diamond\, \mathfrak{a}_1 : \mathscr{C} \longrightarrow \mathscr{C}'$ $\quad$ ($\Diamond \approx$ 'possible')

Toward Theorems

In order to settle the discontinuity debate, one needs a relevant class of theorems whose form should by now be thoroughly unsurprising. Here is a sample member of the class:

Theorem 1: *Humans are discontinuously above chimps.*[2] **Proof**: Chimps cannot reason over arbitrary quantification, & can't invent cognitive calculi in which to do so. Hence the generalized seriated cup challenge is unsolvable for them. ■

Next Steps

Obviously a family of theorems of the same form as Theorem 1 are needed; this we don't have at present. Fortunately, the literature in the relevant parts of cognitive science contains any number of additional problem classes (i.e. additional cases of a relevant first member of a PROB pair) that fit the bill. We are in this regard currently investigating tube-trap problems, on which corvids, it is said, perform impressively. Assuming that discontinuity, *contra* Darwin, will soon be seen to firmly hold as a matter of settled proof, the next phase in our efforts, predictably, is to turn to consideration of whether Darwin's claim C1 is true, and if it is, whether the proposition that human persons are the product of evolution is rational to affirm.

References

Bringsjord, S. (2008*a*), Declarative/Logic-Based Cognitive Modeling, *in* R. Sun, ed., 'The Handbook of Computational Psychology', Cambridge University Press, Cambridge, UK, pp. 127–169.
URL: [3]

Bringsjord, S. (2008*b*), 'The Logicist Manifesto: At Long Last Let Logic-Based AI Become a Field Unto Itself', *Journal of Applied Logic* **6**(4), 502–525.
URL: *http://kryten.mm.rpi.edu/SB_LAI_Manifesto_091808.pdf*

Darwin, C. (1859), *On the Origin of the Species by Means of Natural Selection*, Murray, London, UK.

Darwin, C. (1997), *The Descent of Man*, Prometheus, Amherst, NY. A reprint edition. The book was first published in 1871.

Gentner, T., Fenn, K., Marrgoliash, D. & Nusbaum, H. (n.d.), 'Recursive Syntactic Pattern Learning by Songbirds', *Nature* **440**.

Glymour, C. (1992), *Thinking Things Through*, MIT Press, Cambridge, MA.

Govindarajulu, Naveen Sundar (2016), 'ShadowProver'.
URL: *https://naveensundarg.github.io/prover/*

Govindarajulu, Naveen Sundar (2017), 'Spectra'.
URL: *https://naveensundarg.github.io/Spectra/*

Penn, D., Holyoak, K. & Povinelli, D. (2008), 'Darwin's Mistake: Explaining the Discontinuity Between Human and Nonhuman Minds', *Behavioral and Brain Sciences* **31**, 109–178.

Acknowledgments

The research reported herein has been in part made possible by the support of AFOSR ((FA9550-17-1-0191) for creation and implementation of computational logics and automated-reasoning systems brought to bear on the discontinuity debate. In addition, the development of some of these logics has been made possible by support from ONR.