

On to *Intensional* Logics

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IFLAI
4/1/2021



On those *extensional*
logics, quickly ...

FOL

✓ FOL

✓ FOL

Epistemic + FOL

$B_d B_v B_d V v$

✓ FOL

Epistemic + FOL (for coverage of “killer” robots, later)
 $B_d B_v B_d V v$

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 $B_d B_v B_d V v$

TOL

$\exists X[X(j) \wedge \neg X(m) \wedge S(X)]$

✓ FOL

✓ Epistemic + FOL (for coverage of “killer” robots, later)
 $B_d B_v B_d V v$

TOL
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✓ FOL

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? $\exists X[X(j) \wedge \neg X(m) \wedge S(X)]$



Double-Minded Man

The Contemporary Craft of Creating Characters Meets Today's Cognitive Architectures: A Case Study in Expressivity*

Selmer Bringsjord • John Licato • Alexander Bringsjord

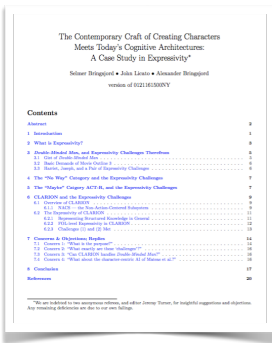
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*We are indebted to two anonymous referees, and editor Jeremy Turner, for insightful suggestions and objections. Any remaining deficiencies are due to our own failings.

Double-Minded Man



Movie Outline - Double-Minded_Man_010316.mvo

Arial 12 Scene Heading 100%

Outline Script Notes Characters FeelFactor Reference Library PowerView Step Cards Story Tasks

1. TWIRL - DAY

68-year-old Harriet Smith sits with two wrinkled hands firmly on the wheel of her rust-eaten Subaru wagon, staring straight ahead through the top level of bifocals as she waits serenely at a red light.

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1. TWIRL - DAY

Step 1 of 3

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A Case Study in Expressivity*

Selmer Bringsjord • John Lewis • Alexander Bringsjord
version of 022101000V

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Double-Minded Man

Double-Minded Man
by
S Bringsjord & A Bringsjord

DRAFT #5
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Double-Minded Man

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The Contemporary Craft of Creating Characters

Memo Today's Cognitive Architecture:

A Case Study in Expressivity*

Silver Stripling • John Linn • Alexander Stripling

version of 022101000V

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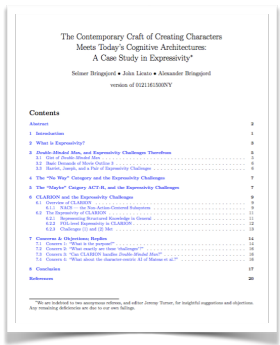
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Double-Minded Man

$$\exists X[X(joseph) \wedge \neg X(m(harriet, joseph)) \wedge Sleazy(X)]$$

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The Contemporary Craft of Creating Characters
Meets Today's Cognitive Architectures:
A Case Study in Expository Writing

Salvatore Strappalà • John Lurie • Alexander Strappalà
version of 02/16/2019

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Double-Minded Man



$$\exists X[X(joseph) \wedge \neg X(m(harriet, joseph)) \wedge Sleazy(X)]$$

1. TWIRL - DAY

68-year-old Harriet Smith sits with two wrinkled hands firmly on the wheel of her rust-eaten Subaru wagon, staring straight ahead through the top level of bifocals as she waits serenely at a red light.

Harriet is alone in the car. To her right is another vehicle, also waiting, in this case to make a right turn; it's a sleek, low-slung, black Camaro.

We are inside the cabin with Harriet. The Subaru's sound system softly plays choral music. Harriet's lips move slightly as she internally sings along, mouthing a slow aria. Her head weaves slightly side to side, in the rhythm with the music.

Things are calm as can be here inside the car with Harriet. There are a pair of well-worn Bibles on the empty passenger seat beside her, one with a gold-lettered 'Harriet' on its leather front cover, the other with a matching 'Joseph' on its front cover.

Harriet's eyes swivel up to the light: still red. We wait with her.

Suddenly there is a piercing SCREECH outside. Harriet jerks her head to the right and we follow her line of sight.

A sleek motorcycle has swerved out of its lane and is now streaking straight for the right side of the Camaro beside Harriet's car.

The bike slams with CLANG into the side of the Camaro. Its rider is flung up and forward into the air, twirling passed Harriet's windshield.

We now watch from Harriet's POV, in slow motion. The black-leather-clad motorcyclist sails by Harriet's windshield, airborne. We see a man's face, clearly: His elephant-hide skin tells us that he is well beyond middle-age. Yet thick, black curls of youthful hair emerge from under his helmet. The rider has only one half of a black, bushy, swept-out, waxed mustache. His eyes are weary and grey, and appear to lock with Harriet's for an instant.

We return to normal speed. The body is now lying on the incoming lane to the left of Harriet's Subaru, perfectly still on the blacktop, the head twisted into an impossible angle. Blood seeps from a nostril. Beside the lifeless head, a BMW medallion lies on the pavement, glinting in the sunlight.

Climbing the k -order Ladder

Climbing the k -order Ladder

a is a llama, as is b , a likes b , and the father of a is a llama as well.

Climbing the k -order Ladder

$Llama(a) \wedge Llama(b) \wedge Likes(a, b) \wedge Llama(fatherOf(a))$

a is a llama, as is b , a likes b , and the father of a is a llama as well.

Climbing the k -order Ladder

ZOL $Llama(a) \wedge Llama(b) \wedge Likes(a, b) \wedge Llama(fatherOf(a))$

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Climbing the k -order Ladder

There's some thing which is a llama and likes b (which is also a llama), and whose father is a llama too.

ZOL $Llama(a) \wedge Llama(b) \wedge Likes(a, b) \wedge Llama(fatherOf(a))$

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$$\exists x [Llama(x) \wedge Llama(b) \wedge Likes(x, b) \wedge Llama(fatherOf(x))]$$

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Things x and y , along with the father of x ,
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Climbing the k -order Ladder

$$\exists x \exists y \exists R [R(x) \wedge R(y) \wedge Likes(x, y) \wedge R(fatherOf(x))]$$

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Climbing the k -order Ladder

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Climbing the k -order Ladder

Things x and y , along with the father of x , share a certain property; and, $x R^2s y$, where R^2 is a positive property.

SOL $\exists x \exists y \exists R [R(x) \wedge R(y) \wedge Likes(x, y) \wedge R(fatherOf(x))]$

Things x and y , along with the father of x , share a certain property (and x likes y).

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Climbing the k -order Ladder

$$\exists x, y \exists R, R^2 [R(x) \wedge R(y) \wedge R^2(x, y) \wedge \textit{Positive}(R^2) \wedge R(\textit{fatherOf}(x))]$$

Things x and y , along with the father of x , share a certain property; and, x R^2 s y , where R^2 is a positive property.

SOL $\exists x \exists y \exists R [R(x) \wedge R(y) \wedge \textit{Likes}(x, y) \wedge R(\textit{fatherOf}(x))]$

Things x and y , along with the father of x , share a certain property (and x likes y).

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Climbing the k -order Ladder

TOL $\exists x, y \exists R, R^2 [R(x) \wedge R(y) \wedge R^2(x, y) \wedge \textit{Positive}(R^2) \wedge R(\textit{fatherOf}(x))]$

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Climbing the k -order Ladder

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SOL $\exists x \exists y \exists R [R(x) \wedge R(y) \wedge \textit{Likes}(x, y) \wedge R(\textit{fatherOf}(x))]$

\mathcal{L}_2 Things x and y , along with the father of x , share a certain property (and x likes y).

FOL $\exists x [Llama(x) \wedge Llama(b) \wedge \textit{Likes}(x, b) \wedge Llama(\textit{fatherOf}(x))]$

\mathcal{L}_1 There's some thing which is a llama and likes b (which is also a llama), and whose father is a llama too.

ZOL $Llama(a) \wedge Llama(b) \wedge \textit{Likes}(a, b) \wedge Llama(\textit{fatherOf}(a))$

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Climbing the k -order Ladder

⋮

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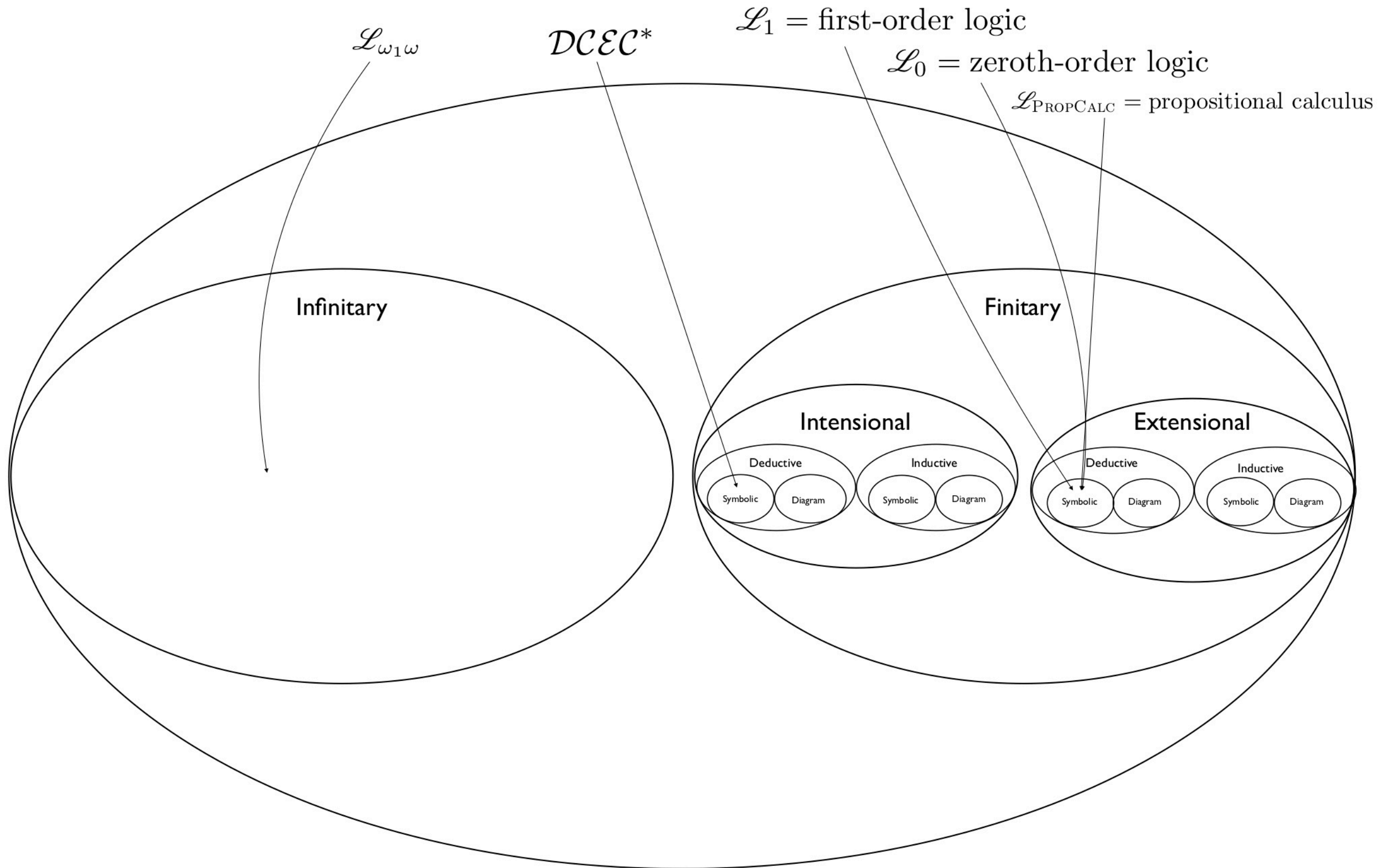
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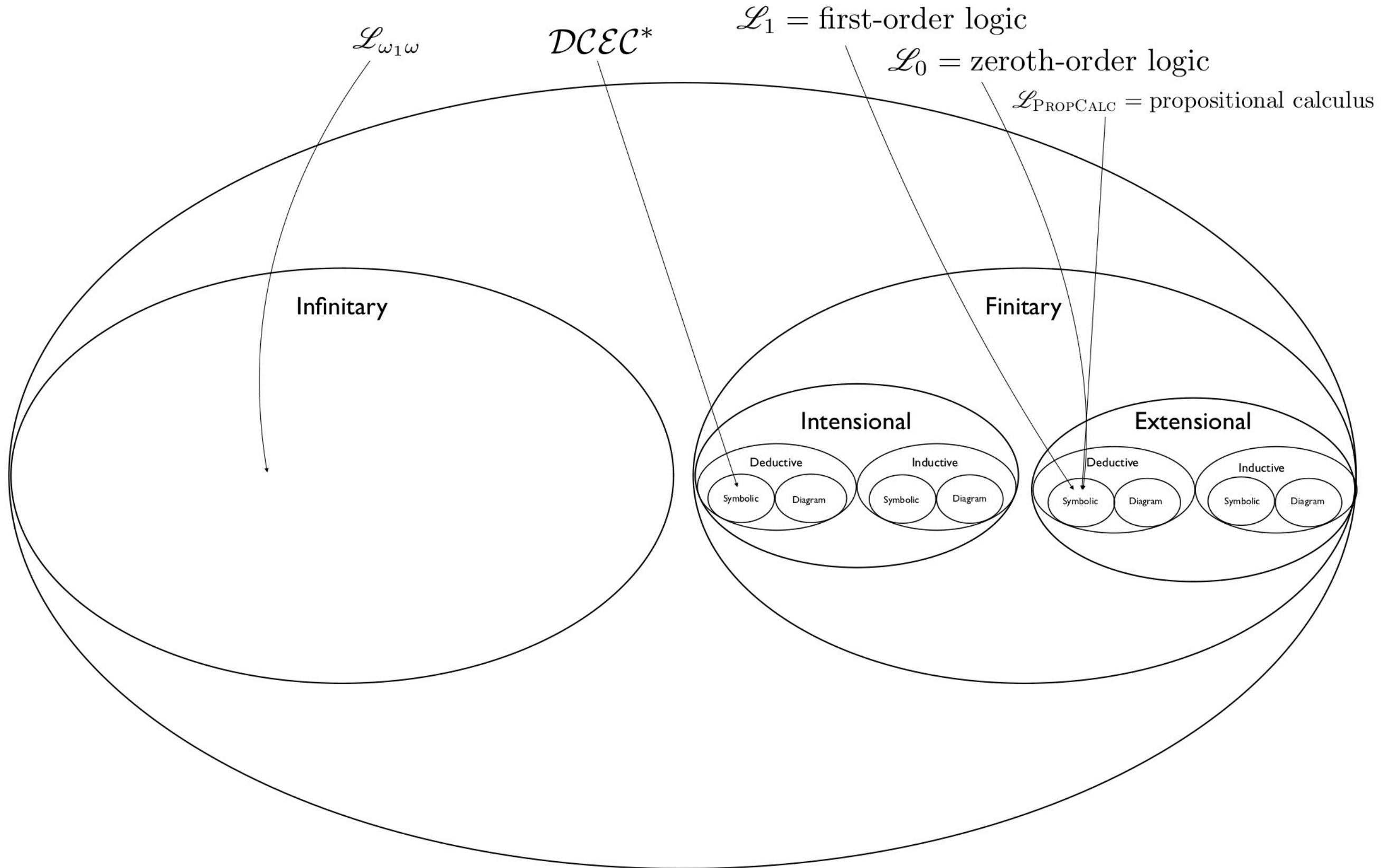
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The Universe of Logics

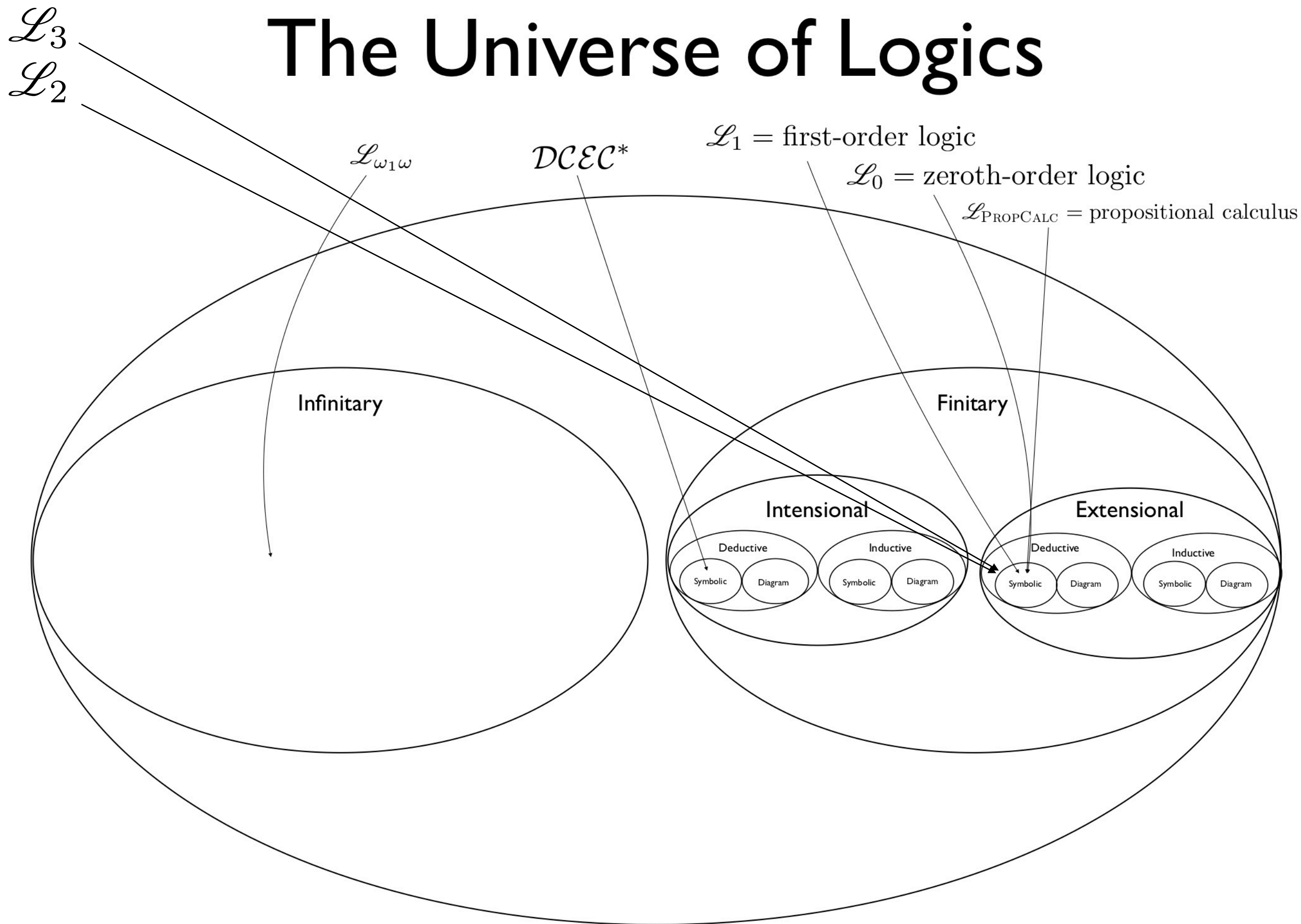


\mathcal{L}_3
 \mathcal{L}_2

The Universe of Logics



The Universe of Logics



Climbing the k -order Ladder

⋮

TOL $\exists x, y \exists R, R^2 [R(x) \wedge R(y) \wedge R^2(x, y) \wedge \textit{Positive}(R^2) \wedge R(\textit{fatherOf}(x))]$

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Climbing the k -order Ladder

⋮

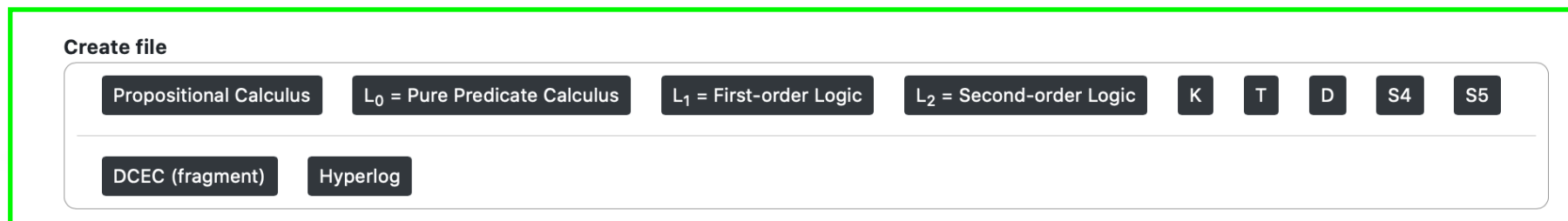
TOL

$\exists x, y \exists R, R^2 [R(x) \wedge R(y) \wedge R^2(x, y) \wedge \text{Positive}(R^2) \wedge R(\text{fatherOf}(x))]$

\mathcal{L}_3

Things x and y , along with the father of x , share a certain property; and, x R^2 s y , where R^2 is a positive property.

SOL



\mathcal{L}_2

Things x and y , along with the father of x , share a certain property (and x likes y).

FOL

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\mathcal{L}_1

There's some thing which is a llama and likes b (which is also a llama), and whose father is a llama too.

ZOL

$Llama(a) \wedge Llama(b) \wedge Likes(a, b) \wedge Llama(\text{fatherOf}(a))$

\mathcal{L}_0

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Climbing the k -order Ladder

⋮

TOL

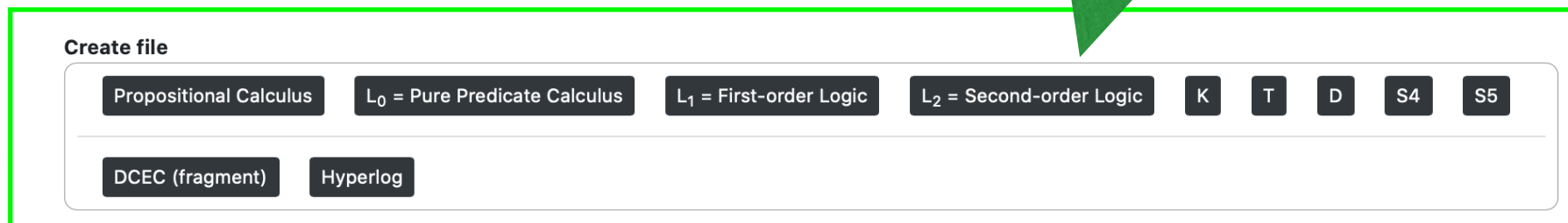
\mathcal{L}_3

$\exists x, y \exists R, R^2 [R(x) \wedge R(y) \wedge R^2(x, y) \wedge \text{Positive}(R^2) \wedge R(\text{fatherOf}(x))]$

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SOL

\mathcal{L}_2



Things x and y , along with the father of x , share a certain property (and x likes y).

FOL

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$\exists x [Llama(x) \wedge Llama(b) \wedge Likes(x, b) \wedge Llama(\text{fatherOf}(x))]$

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ZOL

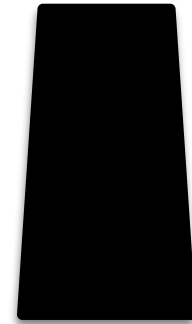
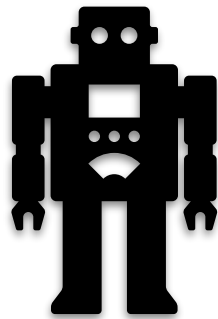
\mathcal{L}_0

$Llama(a) \wedge Llama(b) \wedge Likes(a, b) \wedge Llama(\text{fatherOf}(a))$

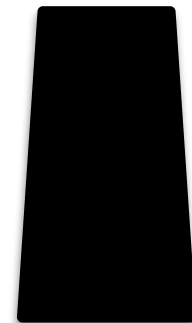
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**Blinky as portal to
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Blinky



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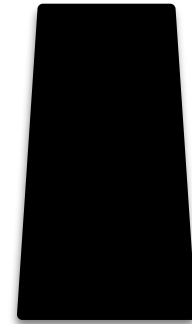
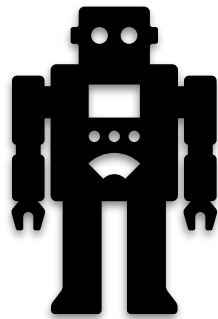


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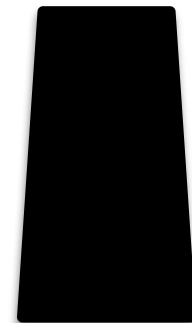


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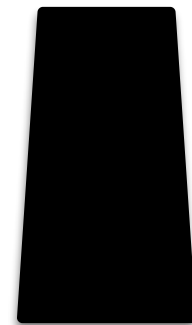
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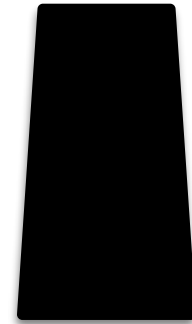
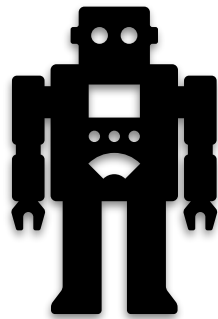
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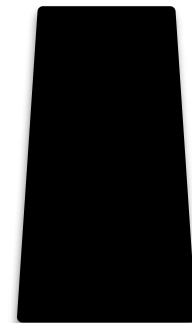
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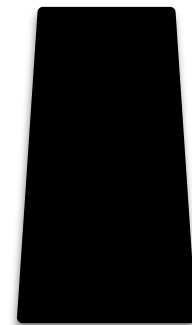
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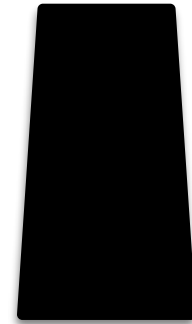
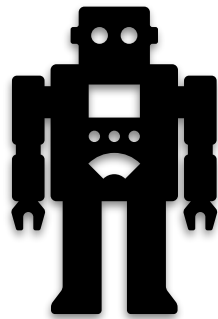


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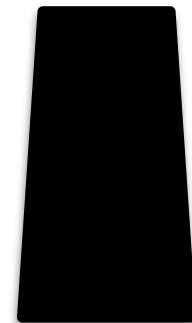


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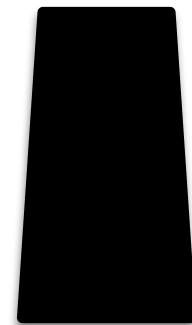
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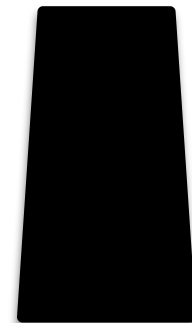
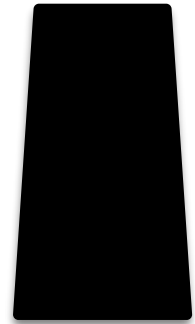
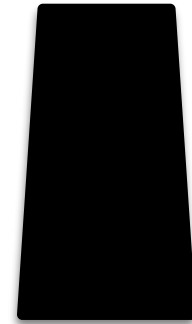
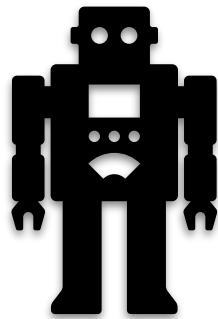


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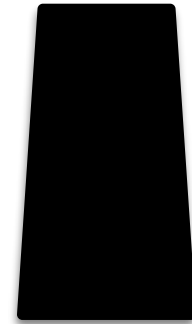
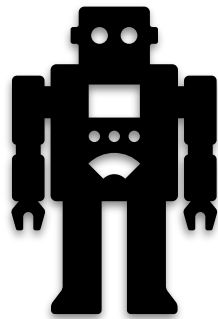
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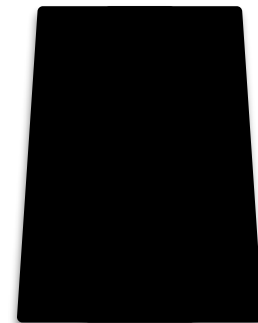
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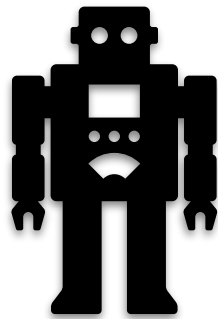
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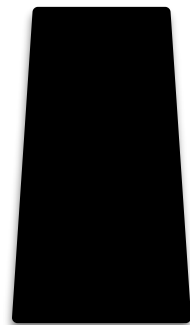
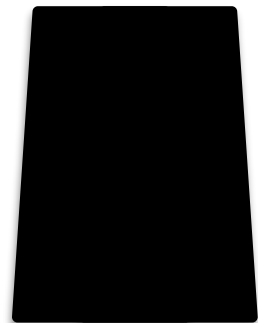
Blinky



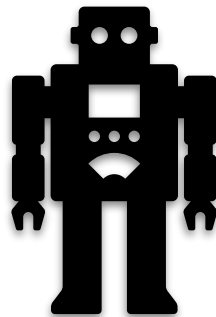
1

2

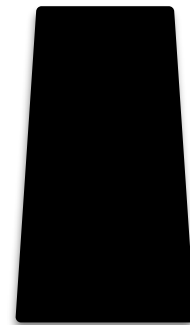
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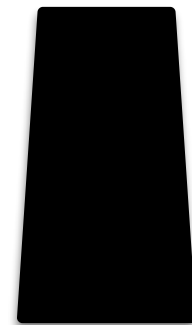
Blinky



1

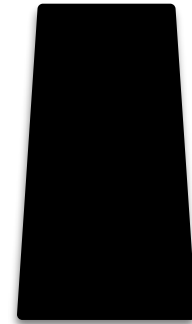
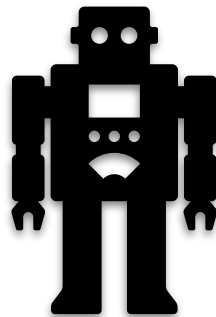


2

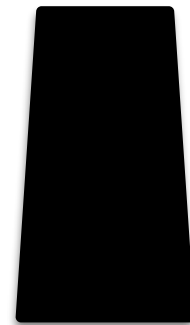


3

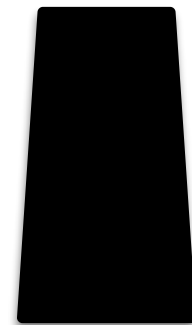
Blinky



1

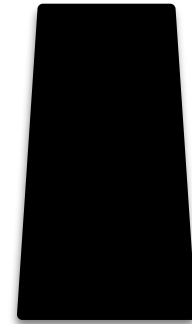
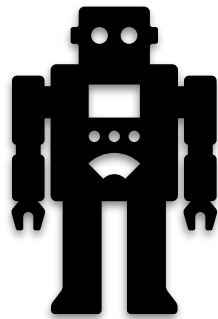


2

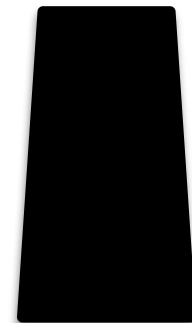


3

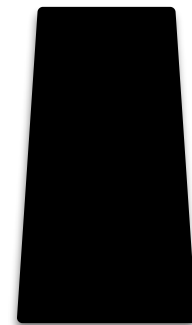
Blinky



1



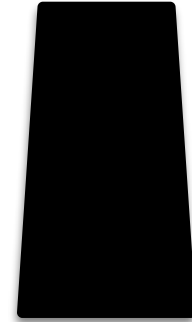
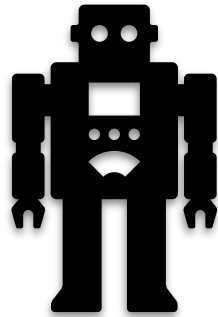
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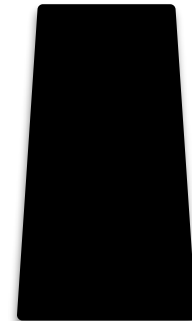
3

The ball is in the cup at location #1.

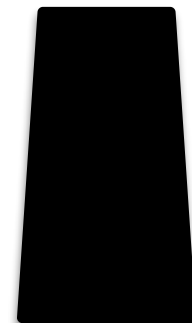
Blinky



1



2

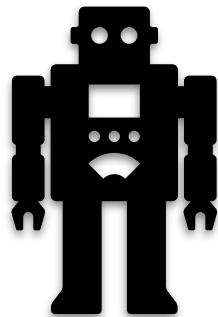


3

The ball is in the cup at location #1.

Loc(ball,1)

Blinky



1



2



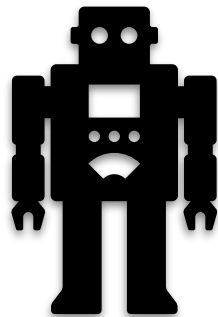
3

The ball is in the cup at location #1.

Loc(ball,1)

(Loc ball 1)

Blinky



1



2



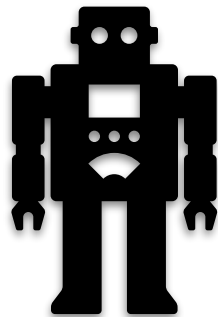
3

The ball is in the cup at location #1.

FALSE Loc(ball,1)

(Loc ball 1)

Blinky



1



2

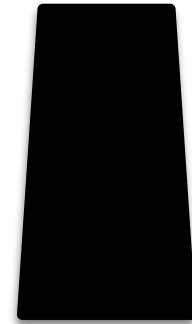
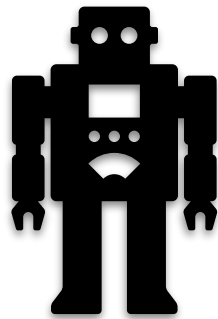


3

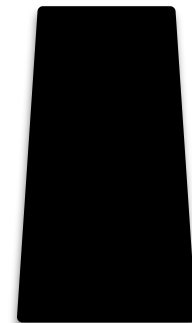
FALSE Loc(ball,1)

(Loc ball 1)

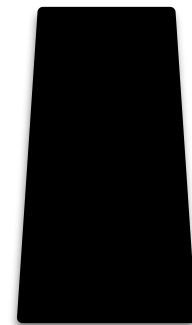
Blinky



1



2

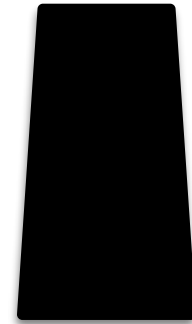
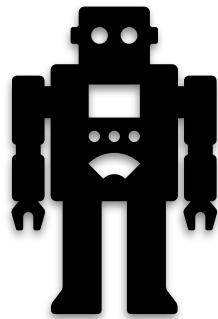


3

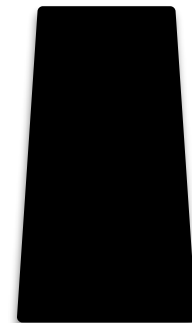
FALSE

(Loc ball 1)

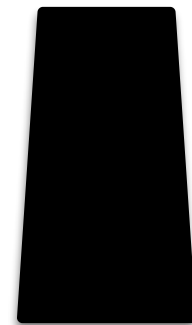
Blinky



1

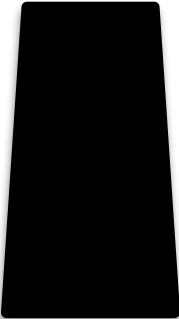


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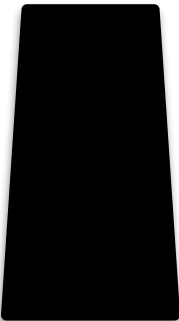


3

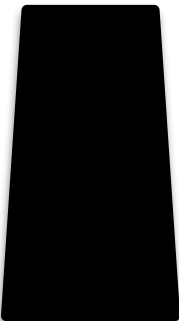
(Loc ball 1)



1

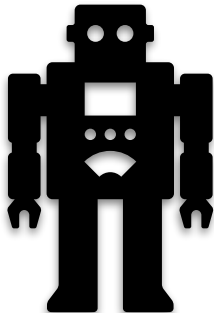


2

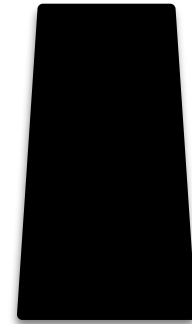
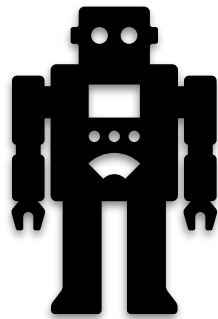


3

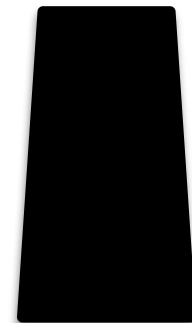
Blinky



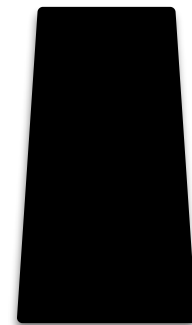
Blinky



1



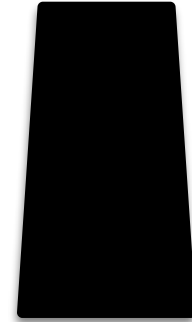
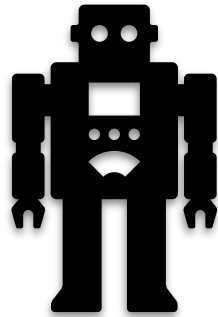
2



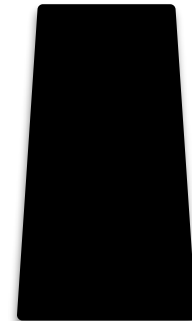
3

The ball is in the cup at location #1 or the ball is at location #3.

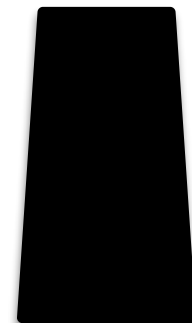
Blinky



1



2

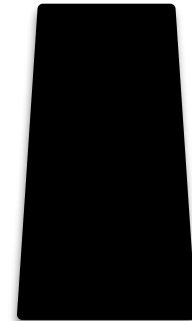
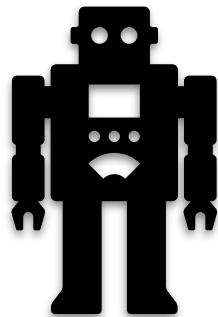


3

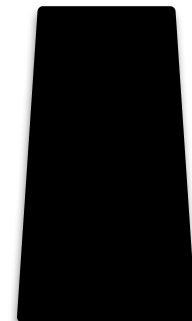
The ball is in the cup at location #1 or the ball is at location #3.

$\text{Loc}(\text{ball}, 1) \vee \text{Loc}(\text{ball}, 3)$

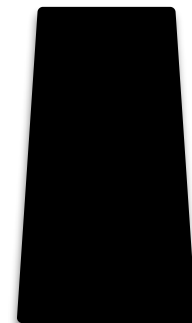
Blinky



1



2



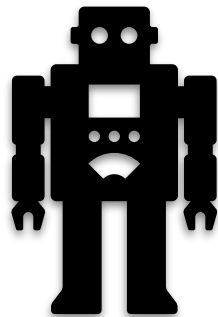
3

The ball is in the cup at location #1 or the ball is at location #3.

$\text{Loc}(\text{ball}, 1) \vee \text{Loc}(\text{ball}, 3)$

(or (Loc ball 1) (Loc ball 3))

Blinky



1



2



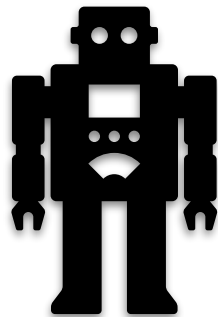
3

The ball is in the cup at location #1 or the ball is at location #3.

FALSE $\text{Loc}(\text{ball}, 1) \vee \text{Loc}(\text{ball}, 3)$

(or (Loc ball 1) (Loc ball 3))

Blinky



1



2

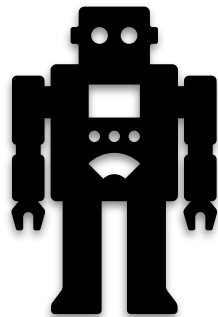


3

FALSE $\text{Loc}(\text{ball}, 1) \vee \text{Loc}(\text{ball}, 3)$

(or (Loc ball 1) (Loc ball 3))

Blinky



1



2

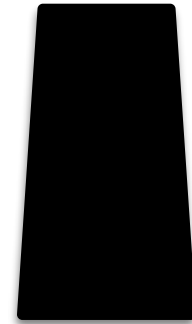
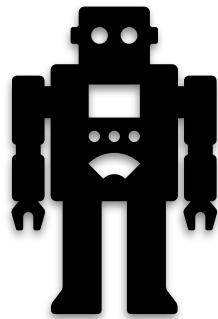


3

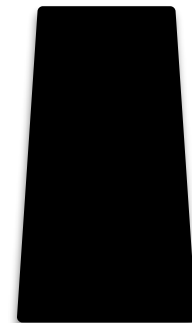
FALSE

(or (Loc ball 1) (Loc ball 3))

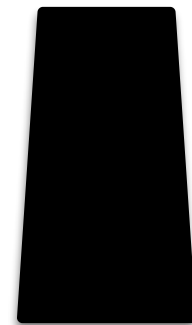
Blinky



1



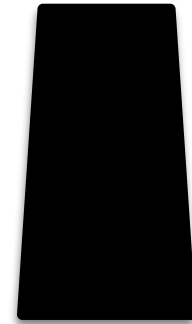
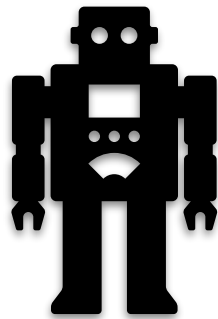
2



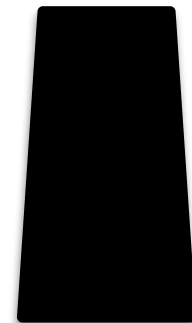
3

FALSE

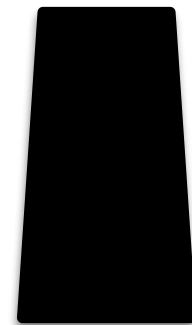
Blinky



1

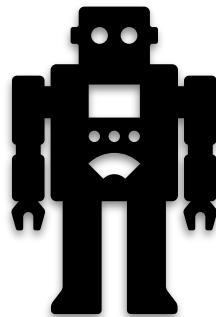


2



3

Blinky



1



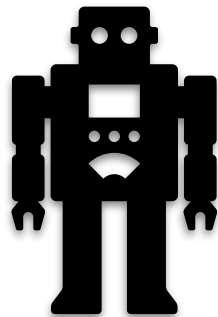
2



3

Blinky believes that the ball is in the cup at location #1.

Blinky



1



2

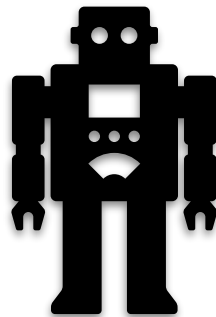


3

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{Loc}(\text{ball}, 1))$

Blinky



1



2



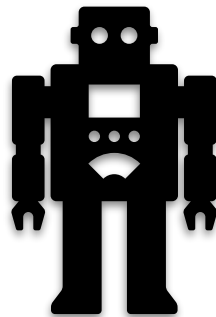
3

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{Loc}(\text{ball}, 1))$

(Believes! Blinky (Loc ball 1))

Blinky



1



2



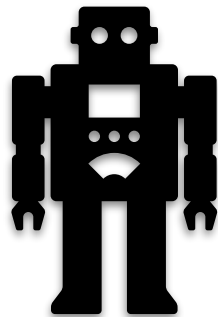
3

Blinky believes that the ball is in the cup at location #1.

??? B(blinky, Loc(ball,1))

(Believes! Blinky (Loc ball 1))

Blinky



1



2



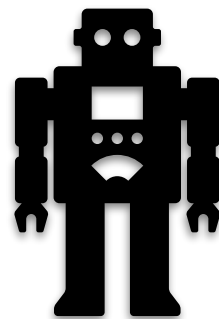
3

Blinky believes that the ball is in the cup at location #1.

??? B(blinky, Loc(ball,1))

(Believes! Blinky (Loc ball 1))

Blinky



1



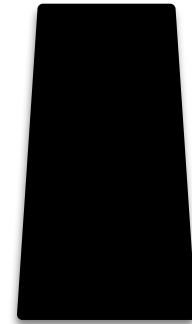
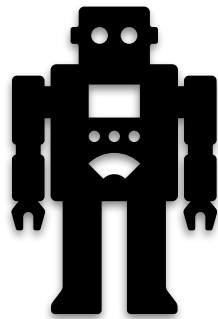
2



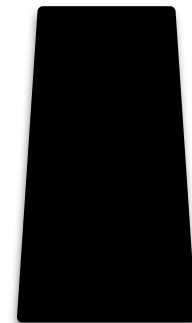
3

In extensional logics, what is denoted is conflated with meaning (the latter being naïvely compositional), but intensional attitudes like *believes*, *knows*, *hopes*, *fears*, etc cannot be represented and reasoned over smoothly (e.g. without fear of inconsistency rising up).

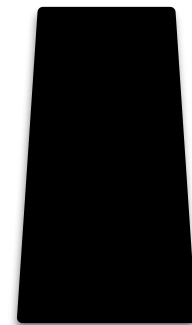
Blinky



1

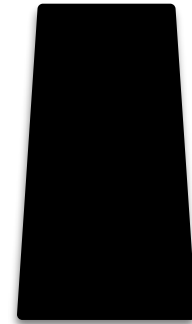
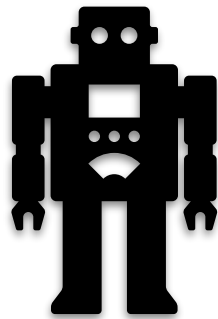


2

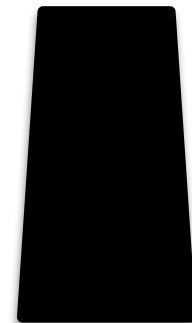


3

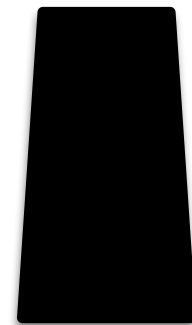
Blinky



1



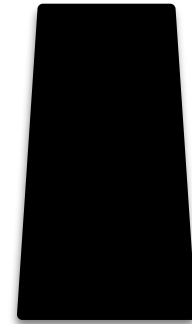
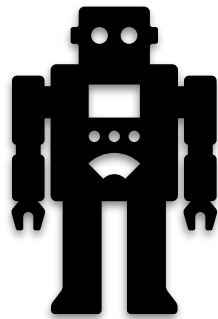
2



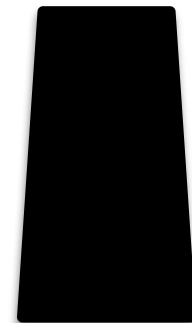
3



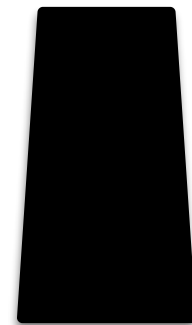
Blinky



1

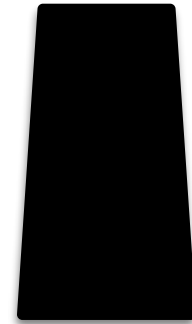
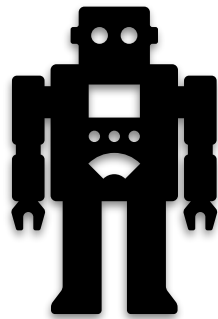


2

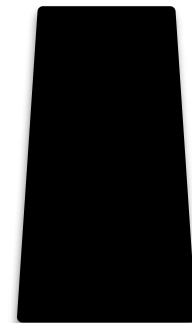


3

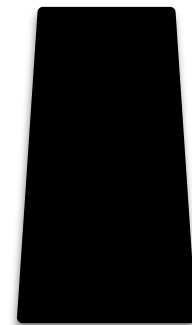
Blinky



1

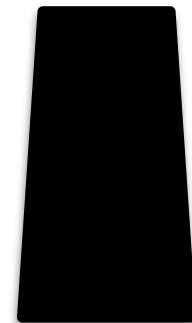
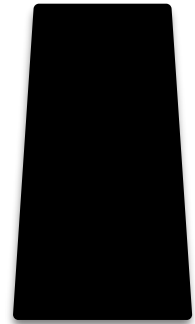
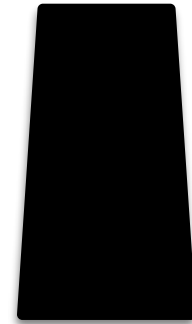
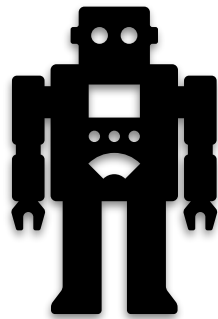


2



3

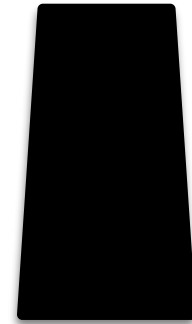
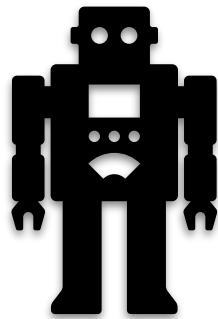
Blinky



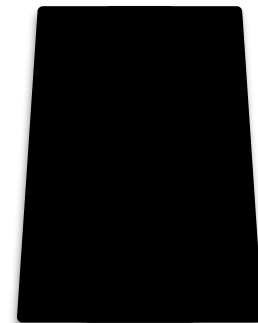
2

3

Blinky



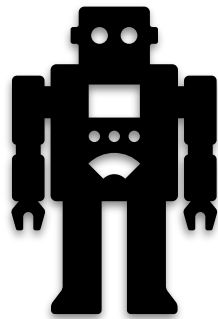
1



2

3

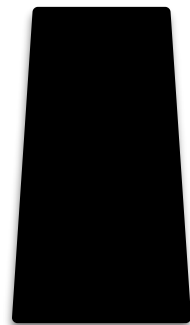
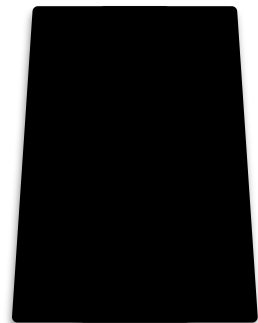
Blinky



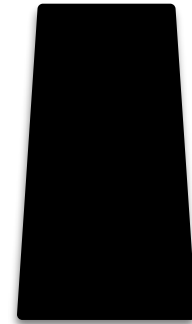
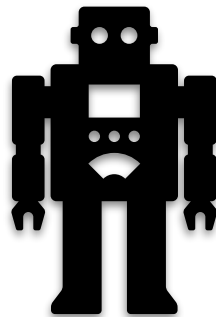
1

2

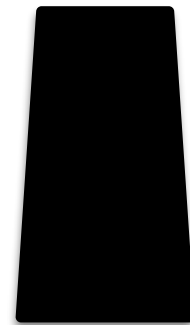
3



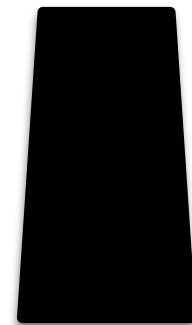
Blinky



1

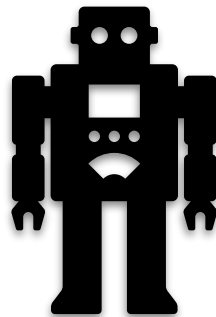


2

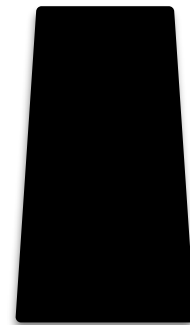


3

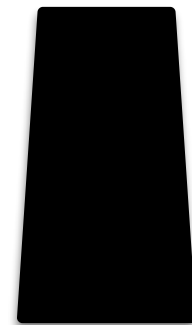
Blinky



1

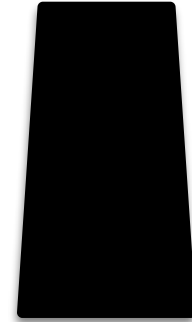
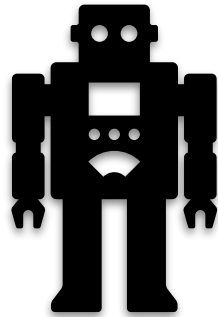


2

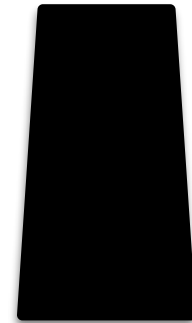


3

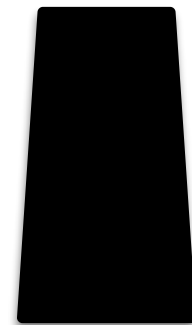
Blinky



1



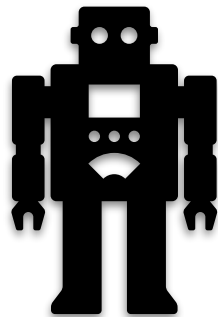
2



3

Blinky believes that the ball is in the cup at location #1.

Blinky



1



2

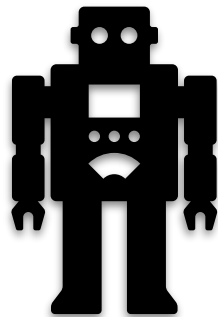


3

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{loc-ball-1})$

Blinky



1



2



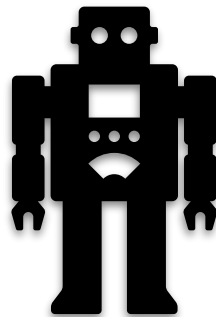
3

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{loc-ball-1})$

(Believes! blinky loc-ball-1)

Blinky



1



2



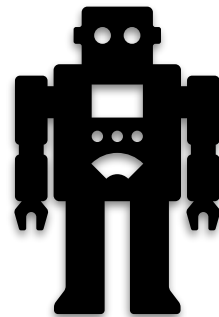
3

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{loc-ball-1})$

(Believes! blinky loc-ball-1)

Blinky



1



2



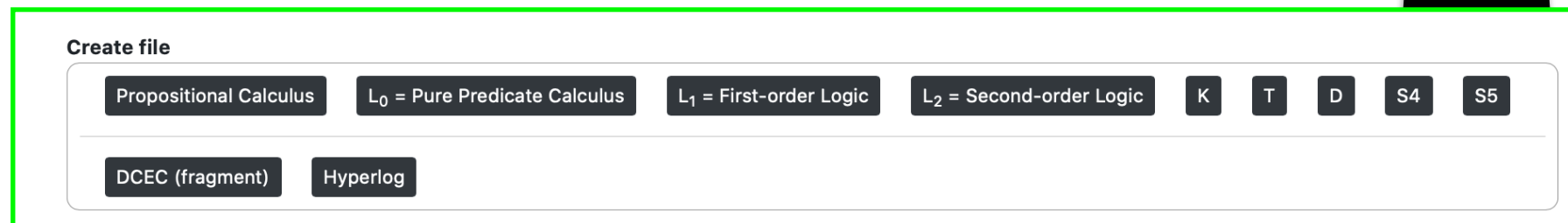
3

In intensional logics, meaning and designation are separated, and compositionality is abandoned.

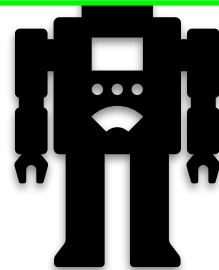
Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{loc-ball-1})$

(Believes! blinky loc-ball-1)



Blinky



1

2

3

In intensional logics, meaning and designation are separated, and compositionality is abandoned.

Blinky believes that the ball is in the cup at location #1.

$B(\text{blinky}, \text{loc-ball-1})$

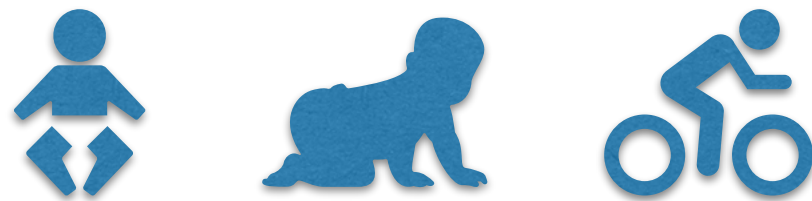
(Believes! blinky loc-ball-1)



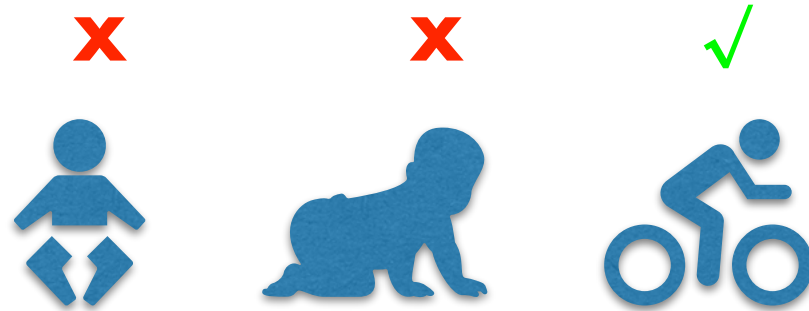
In intensional logics, meaning and designation are separated, and compositionality is abandoned.

False Belief Task Demands Intensional Logic ...

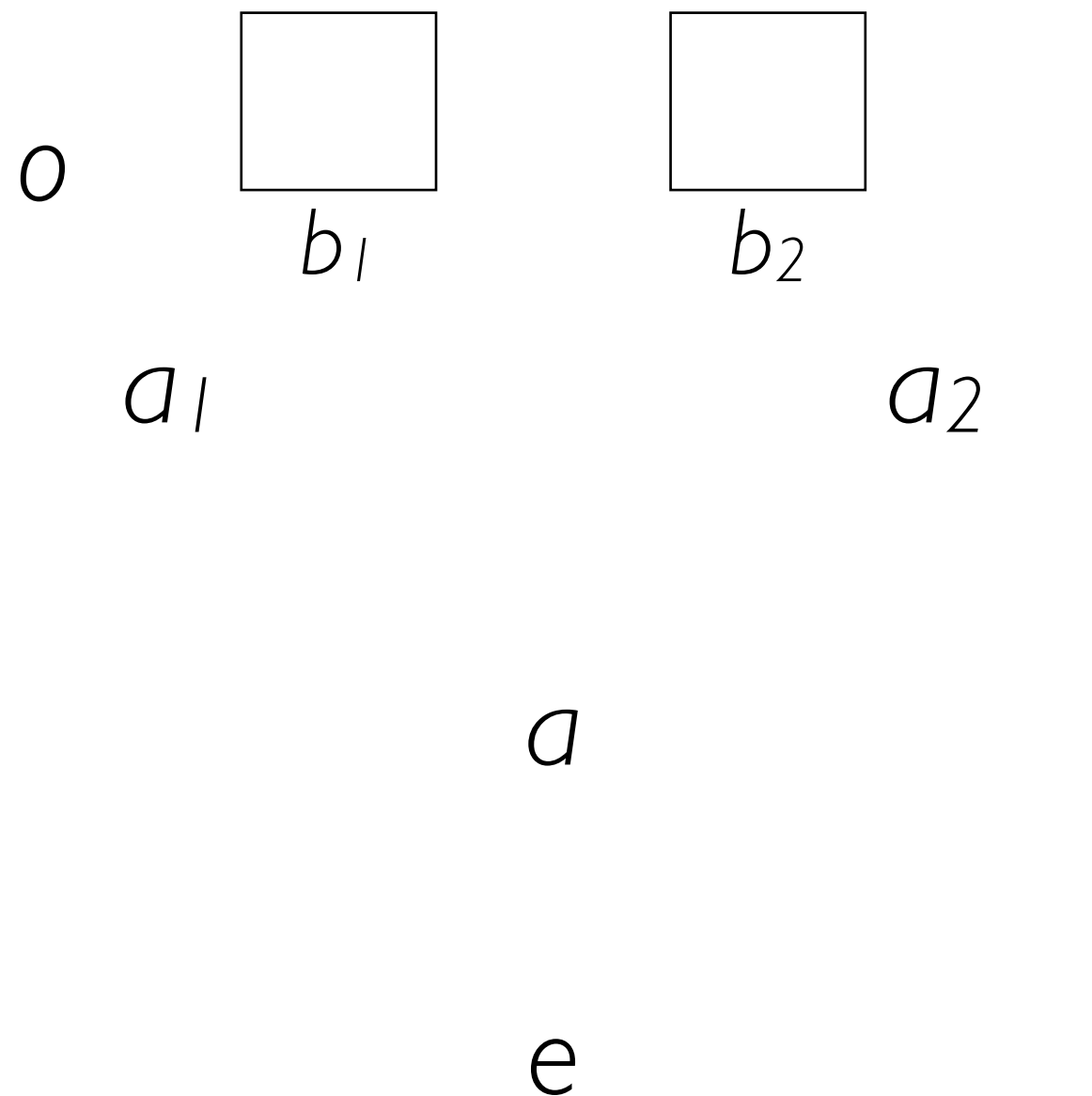
False Belief Task Demands Intensional Logic ...



False Belief Task Demands Intensional Logic ...

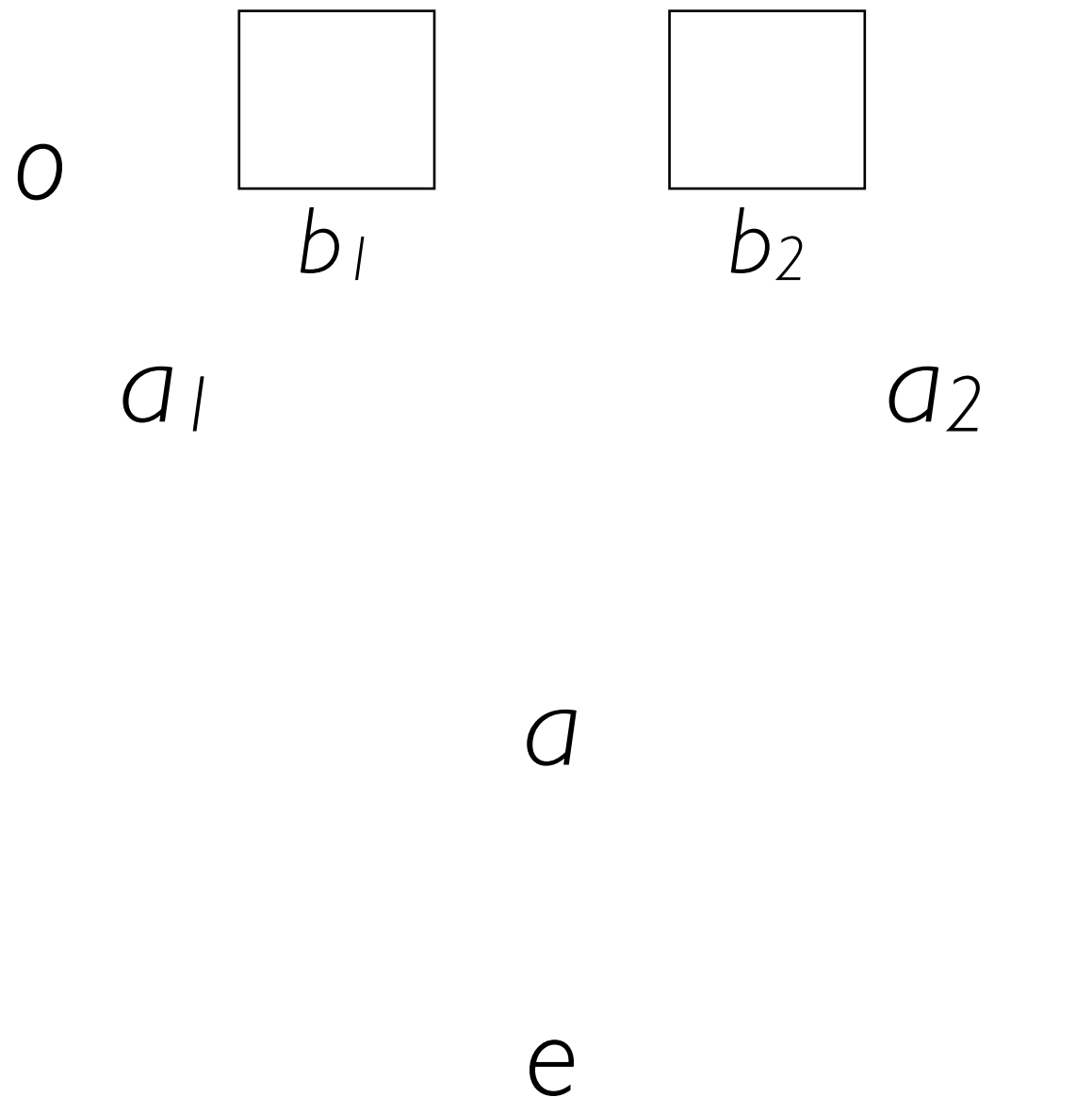


Framework for FBT^0_1



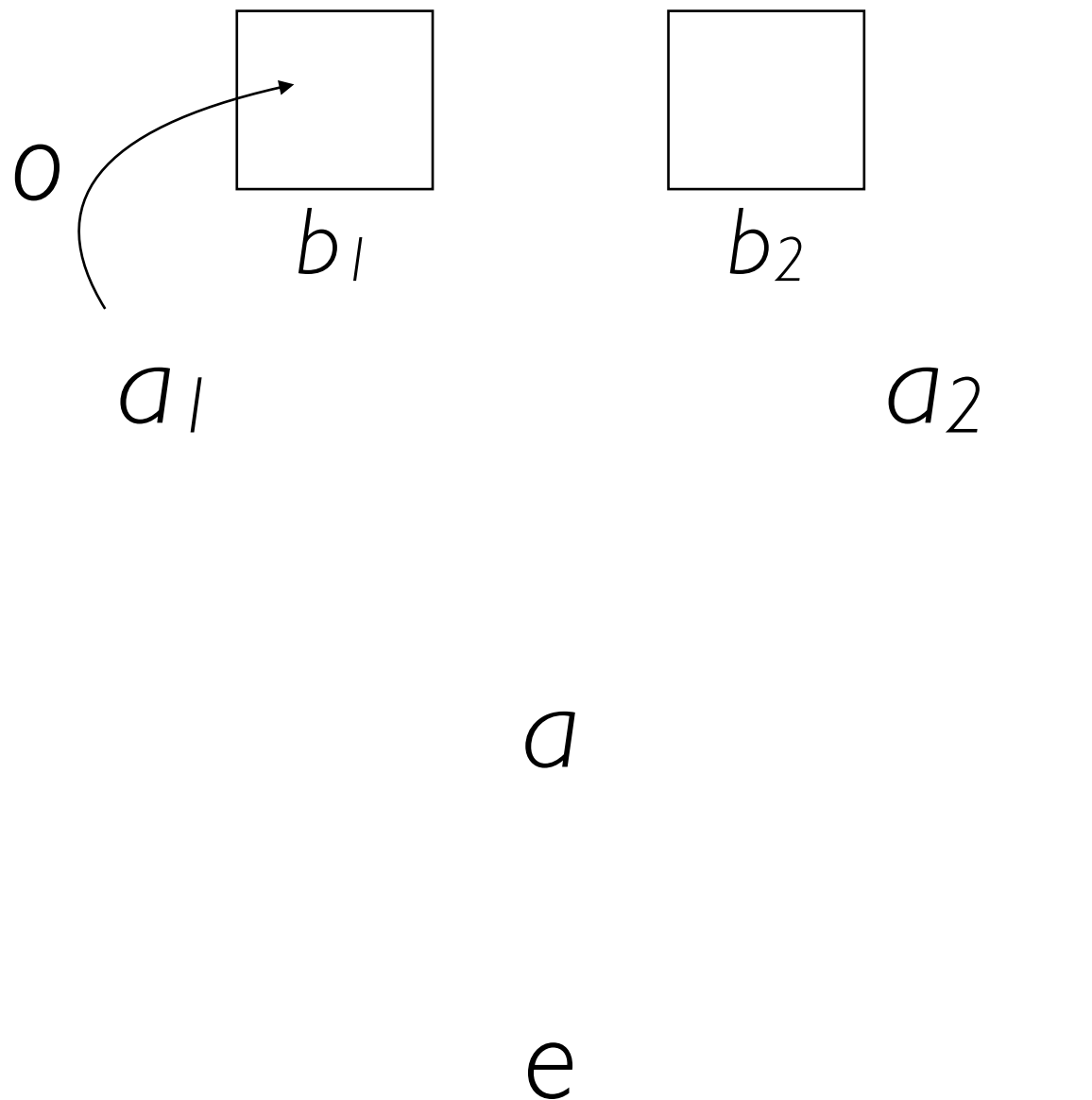
Framework for FBT^0_1

(five timepoints)



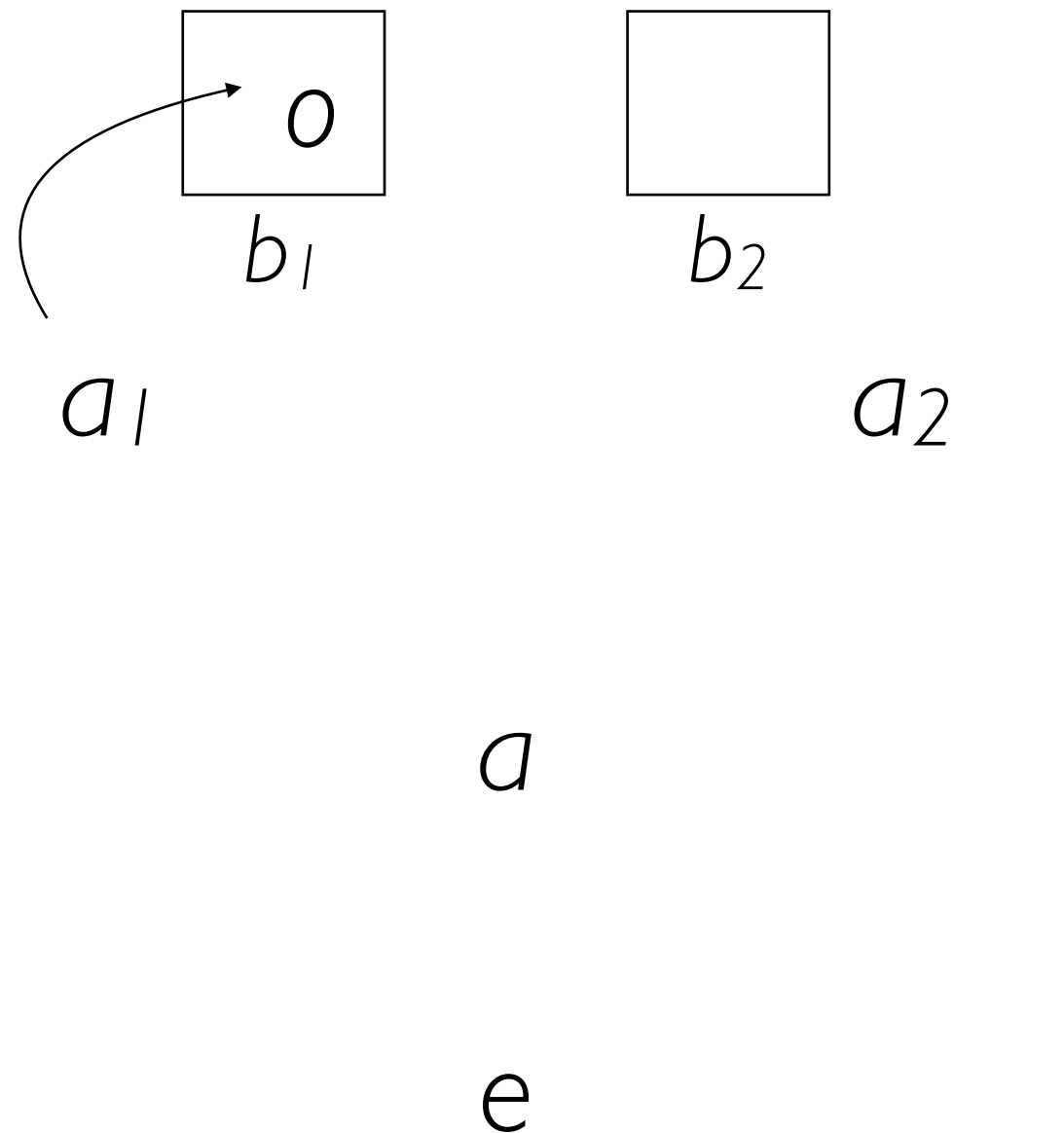
Framework for FBT^0_1

(five timepoints)



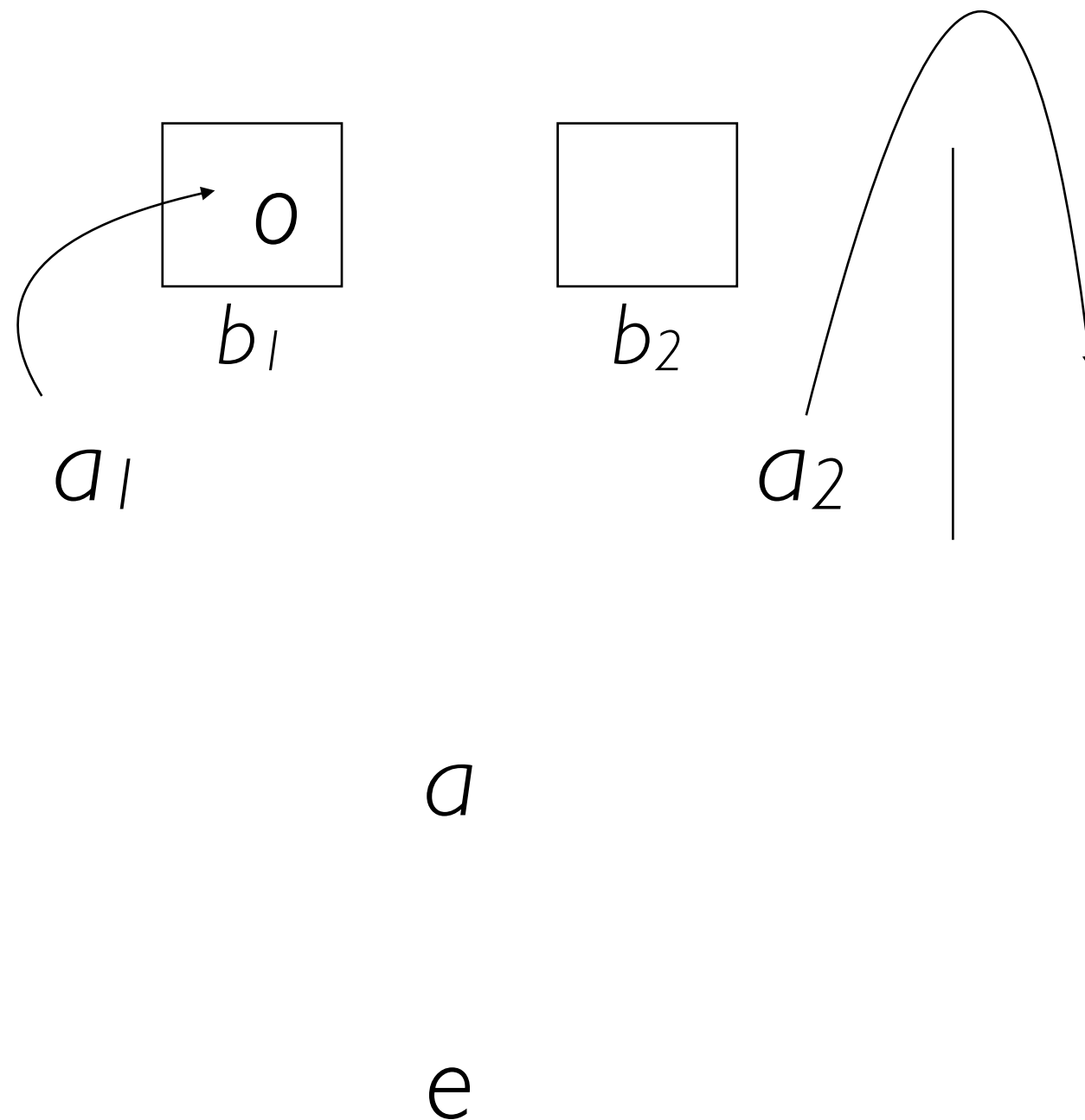
Framework for FBT^0_1

(five timepoints)



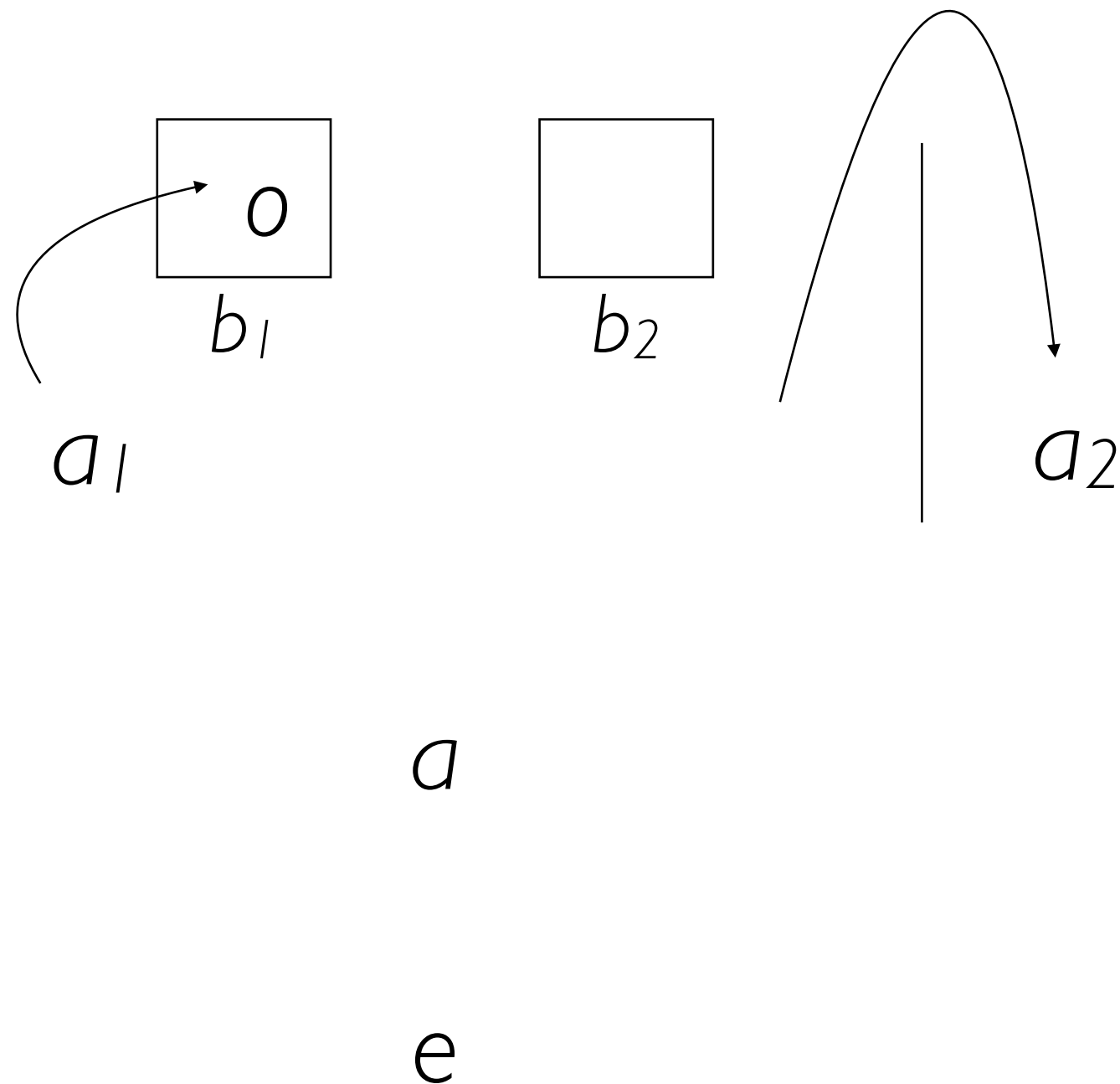
Framework for FBT^0_1

(five timepoints)



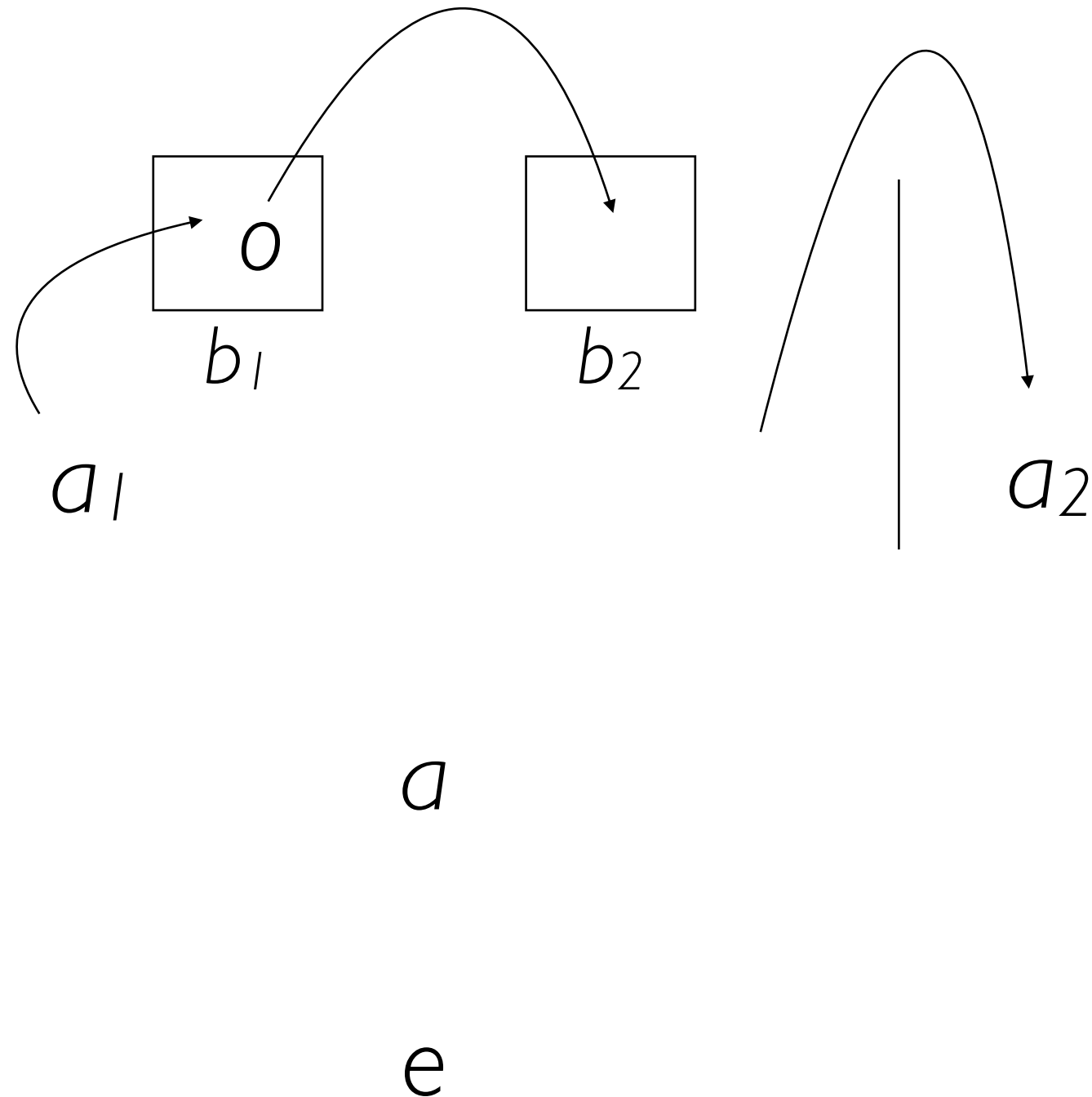
Framework for FBT^0_1

(five timepoints)



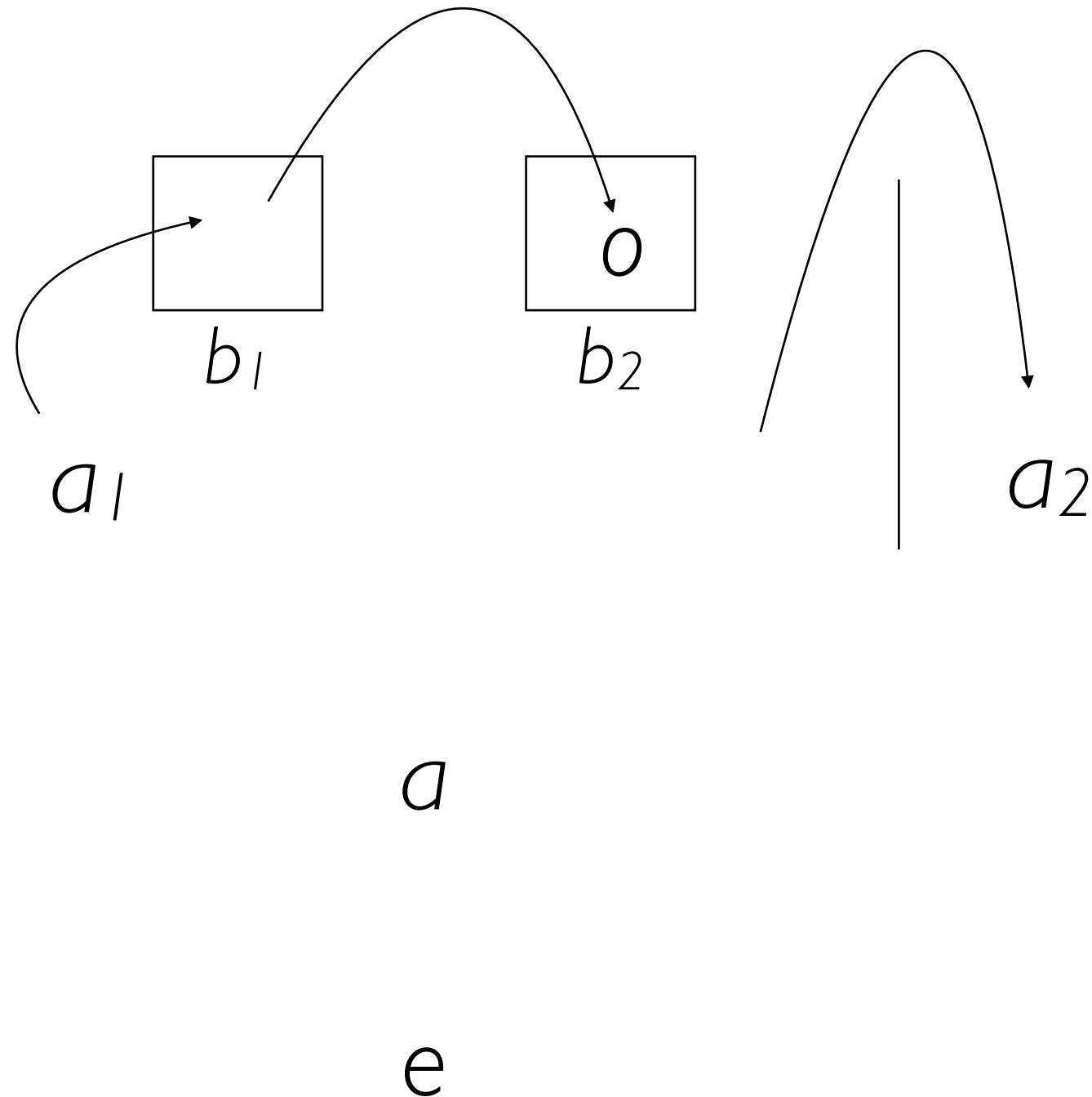
Framework for FBT^0_1

(five timepoints)



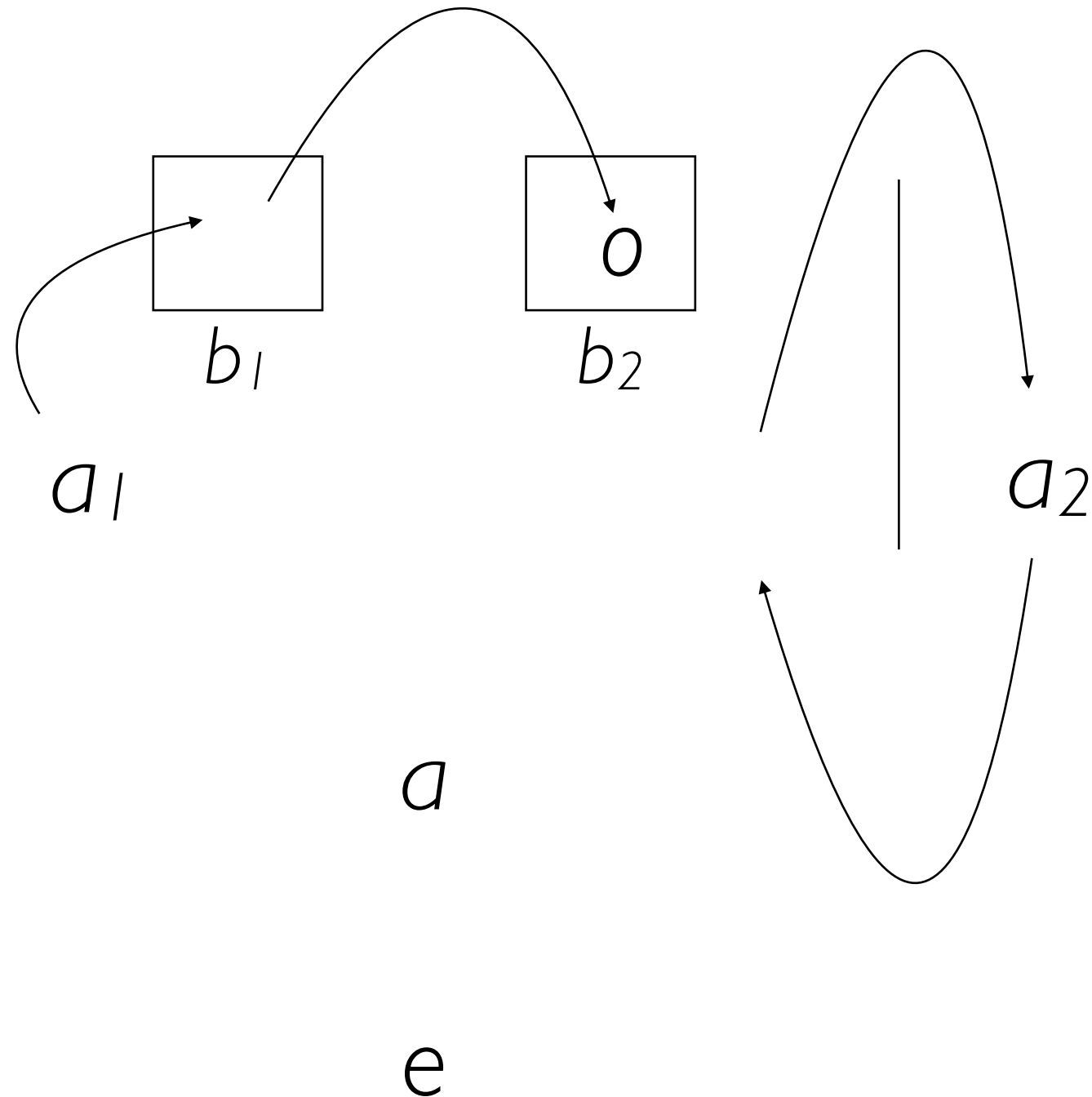
Framework for FBT^0_1

(five timepoints)



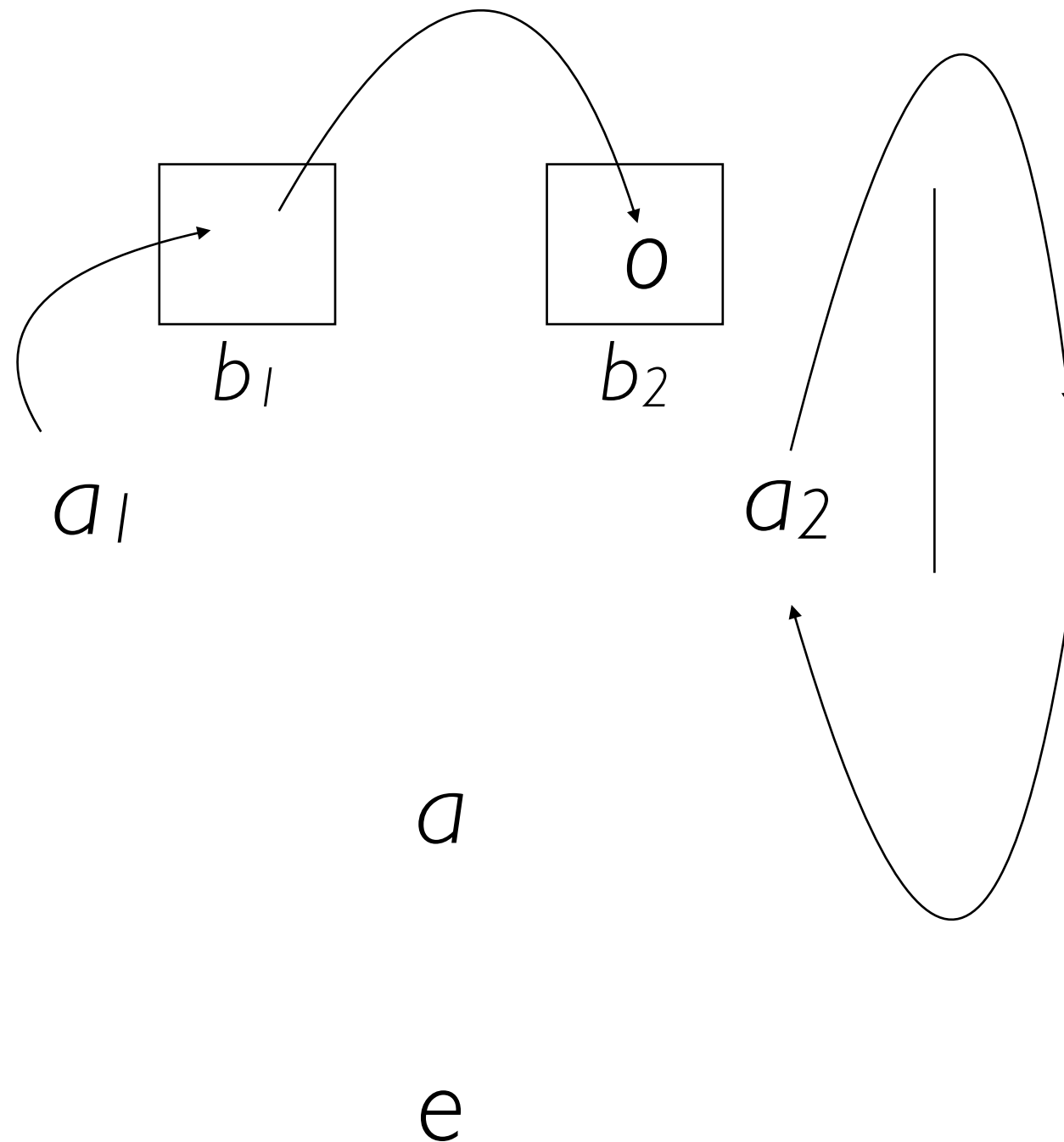
Framework for FBT^0_1

(five timepoints)



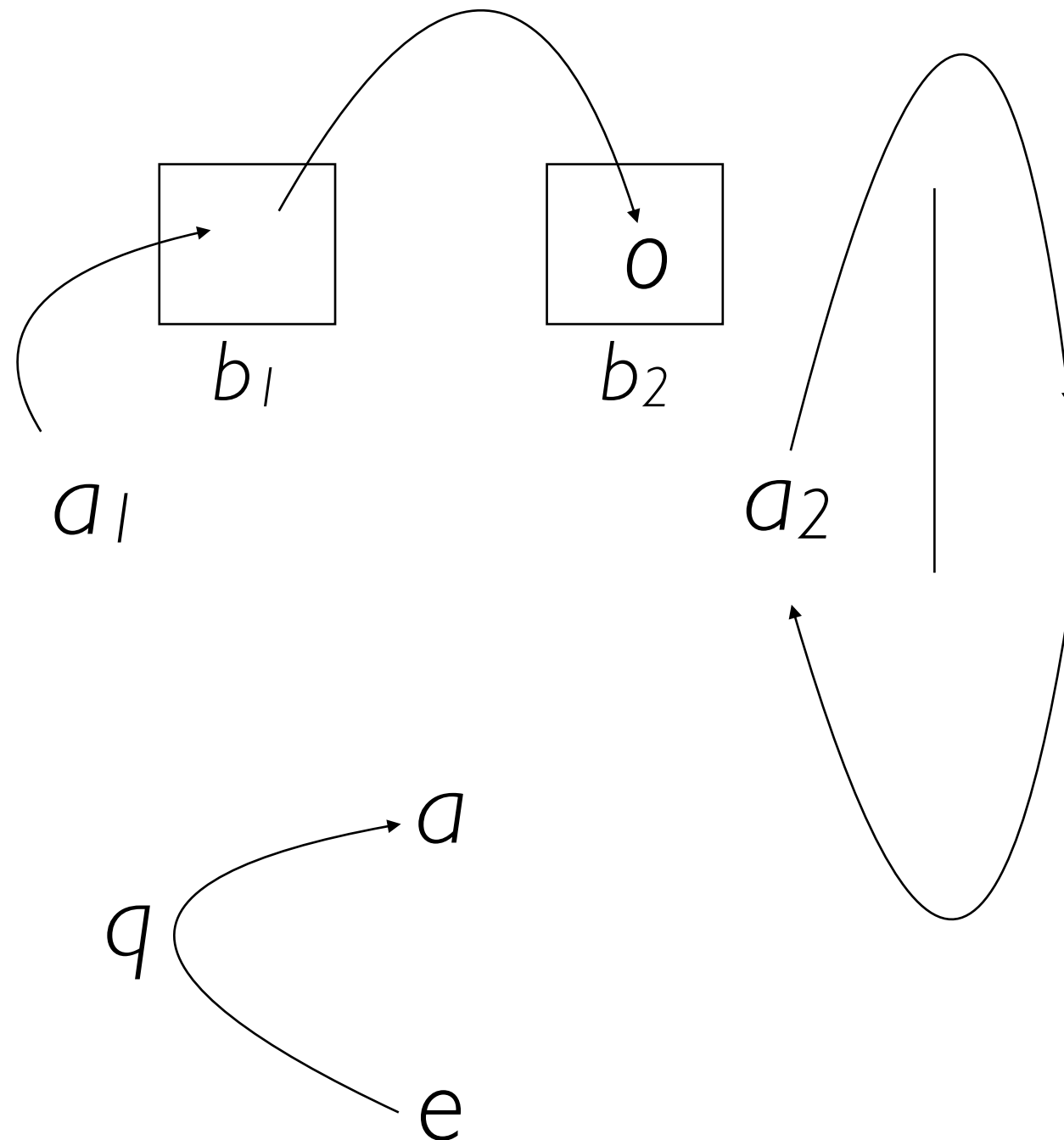
Framework for FBT^0_1

(five timepoints)



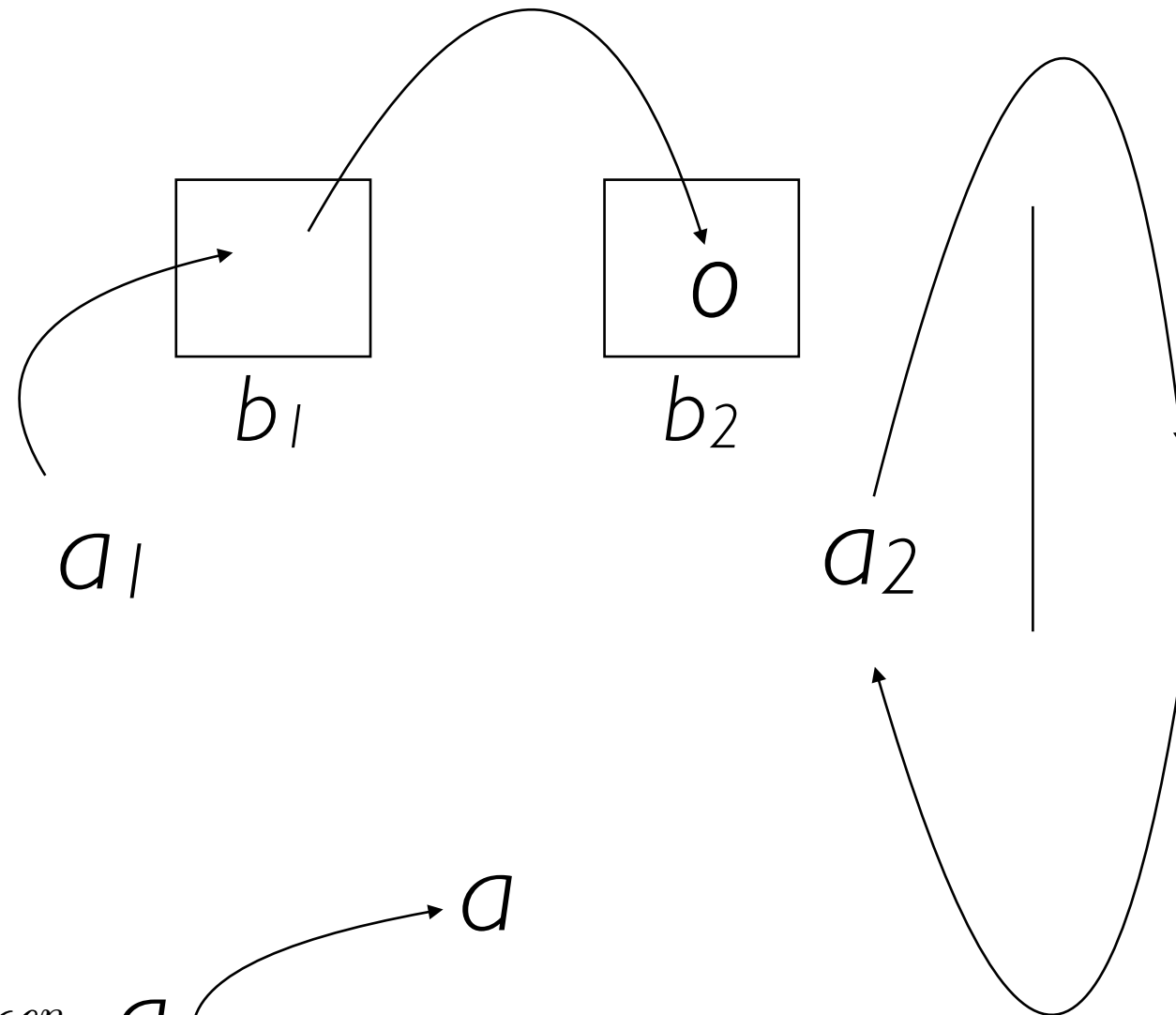
Framework for FBT^0_1

(five timepoints)

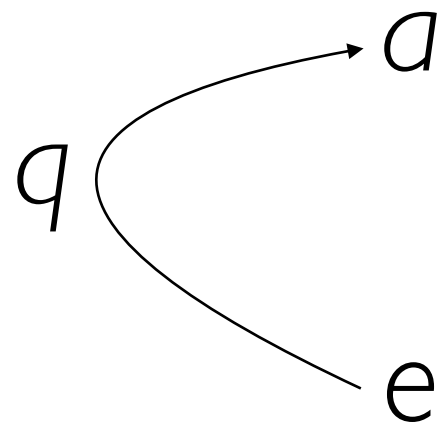


Framework for FBT^0_1

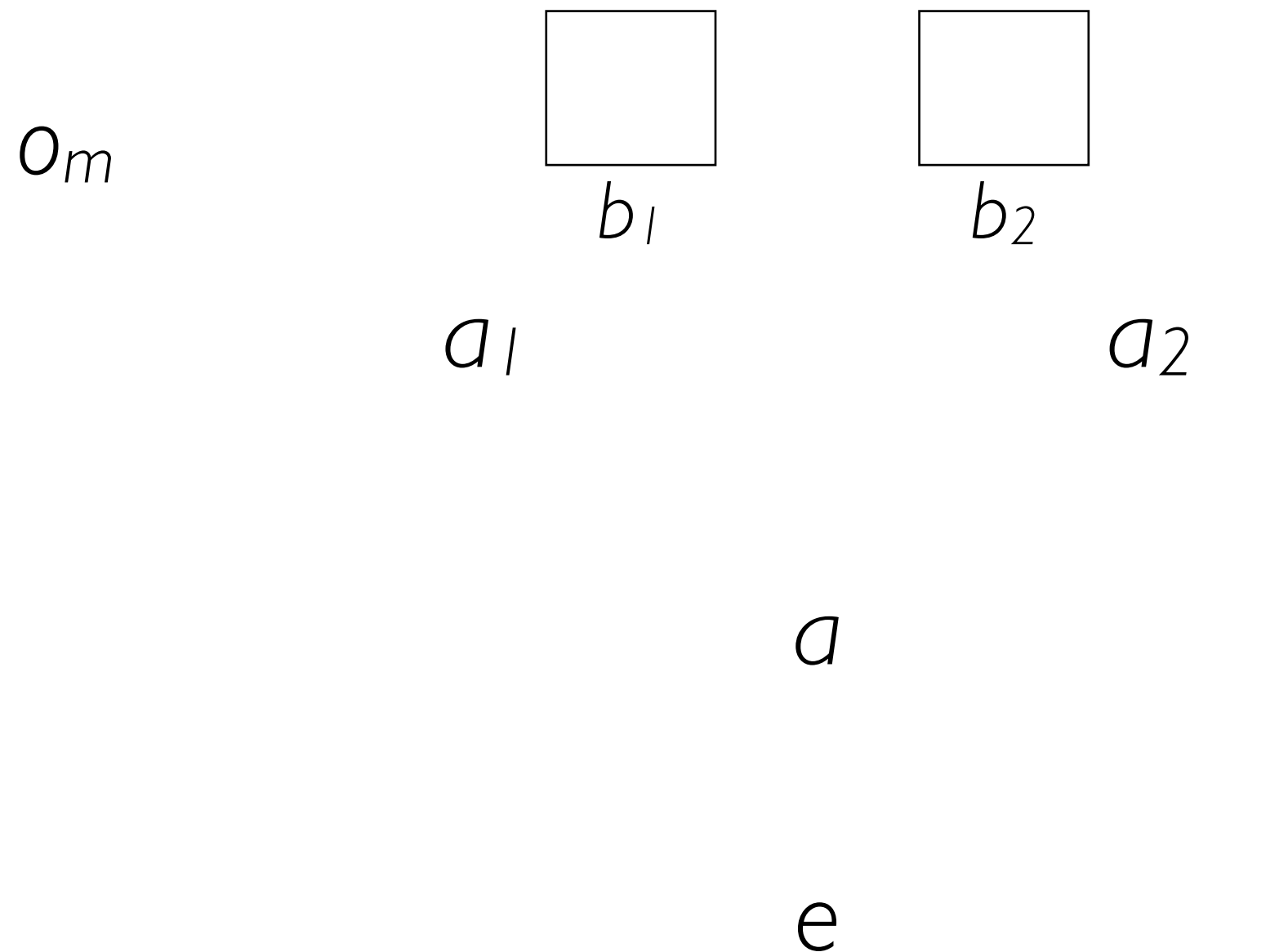
(five timepoints)



q a formula in modal \mathcal{L}^n

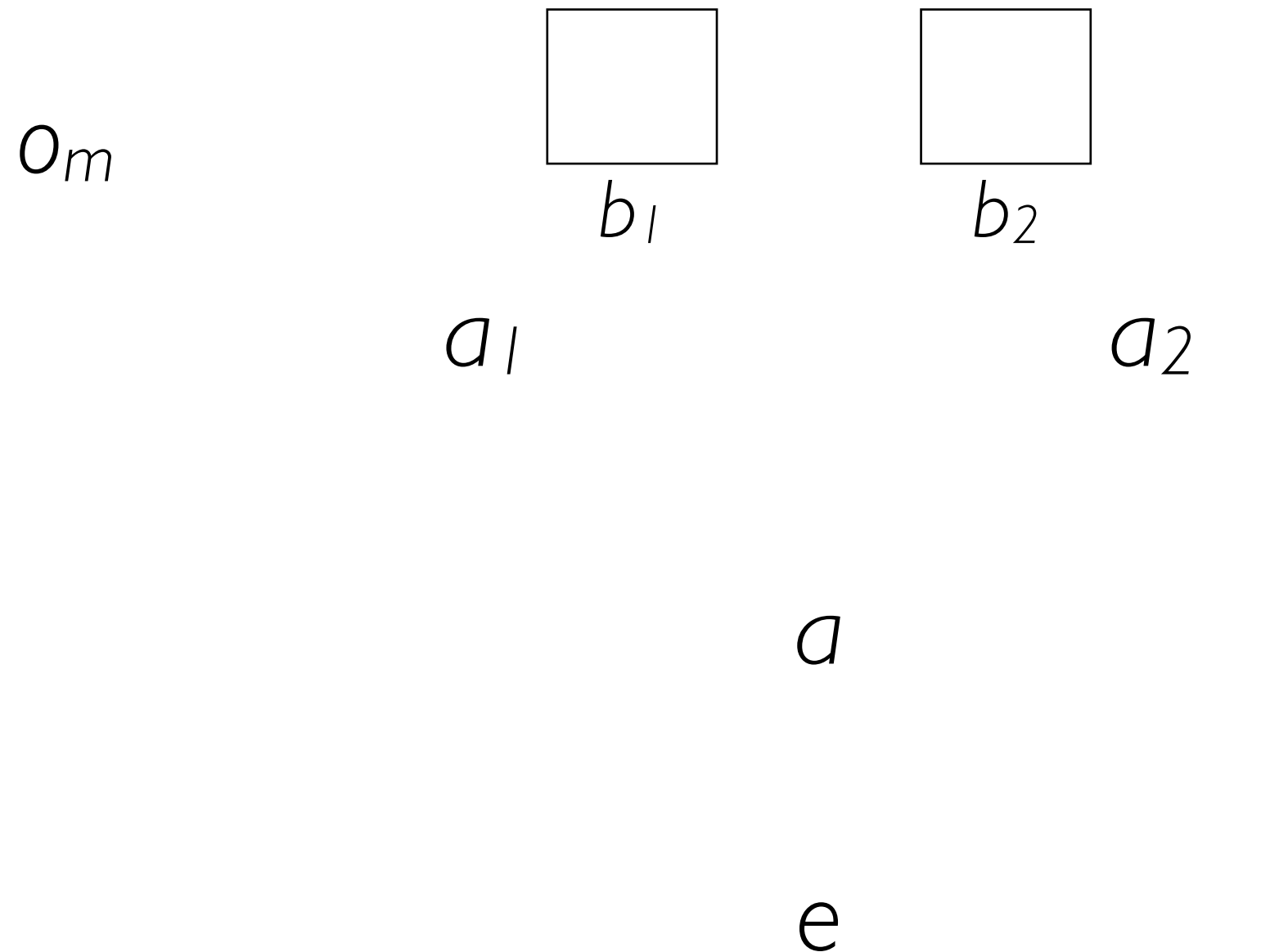


Framework for FBT₁



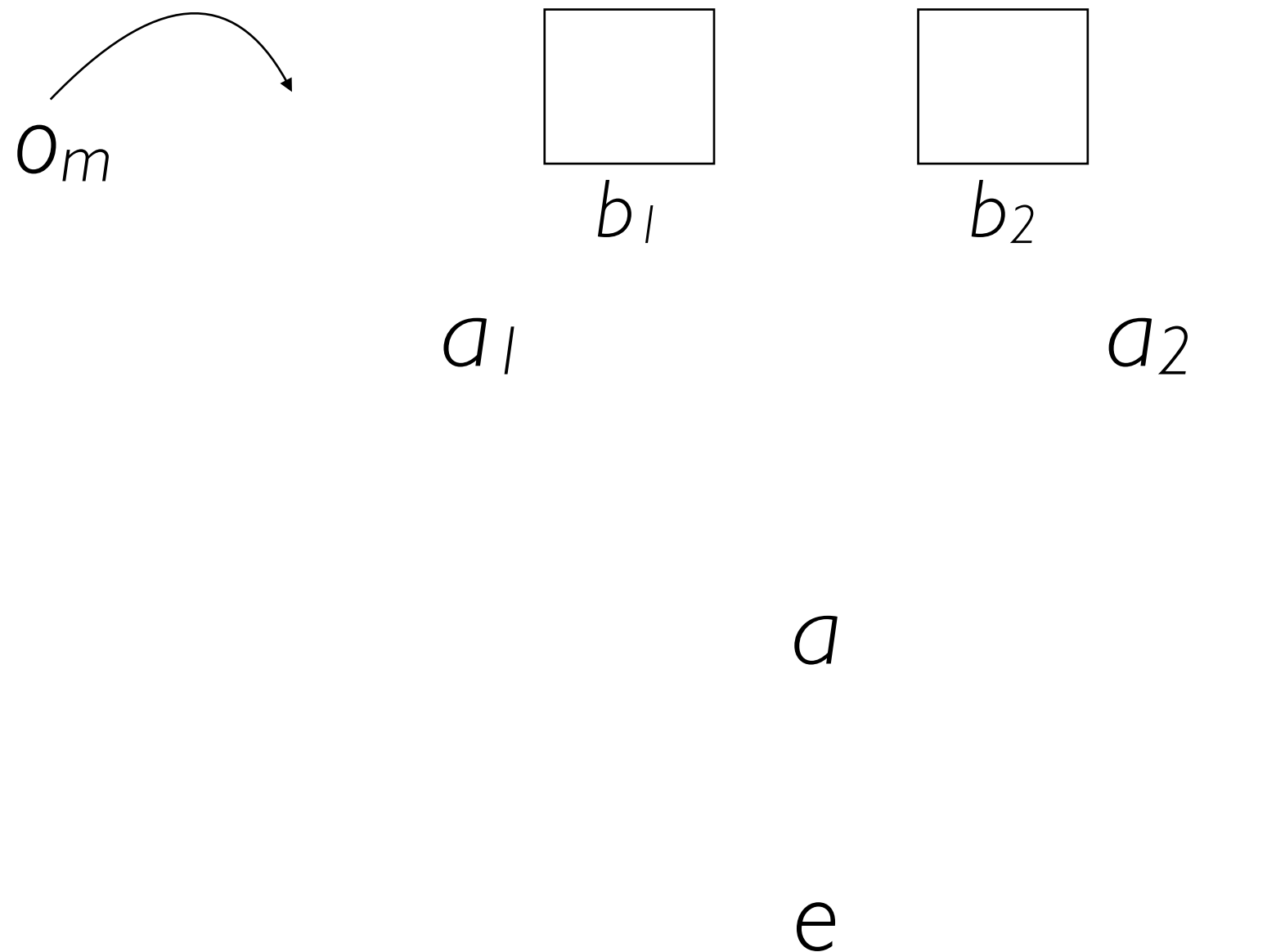
Framework for FBT₁

(six timepoints)



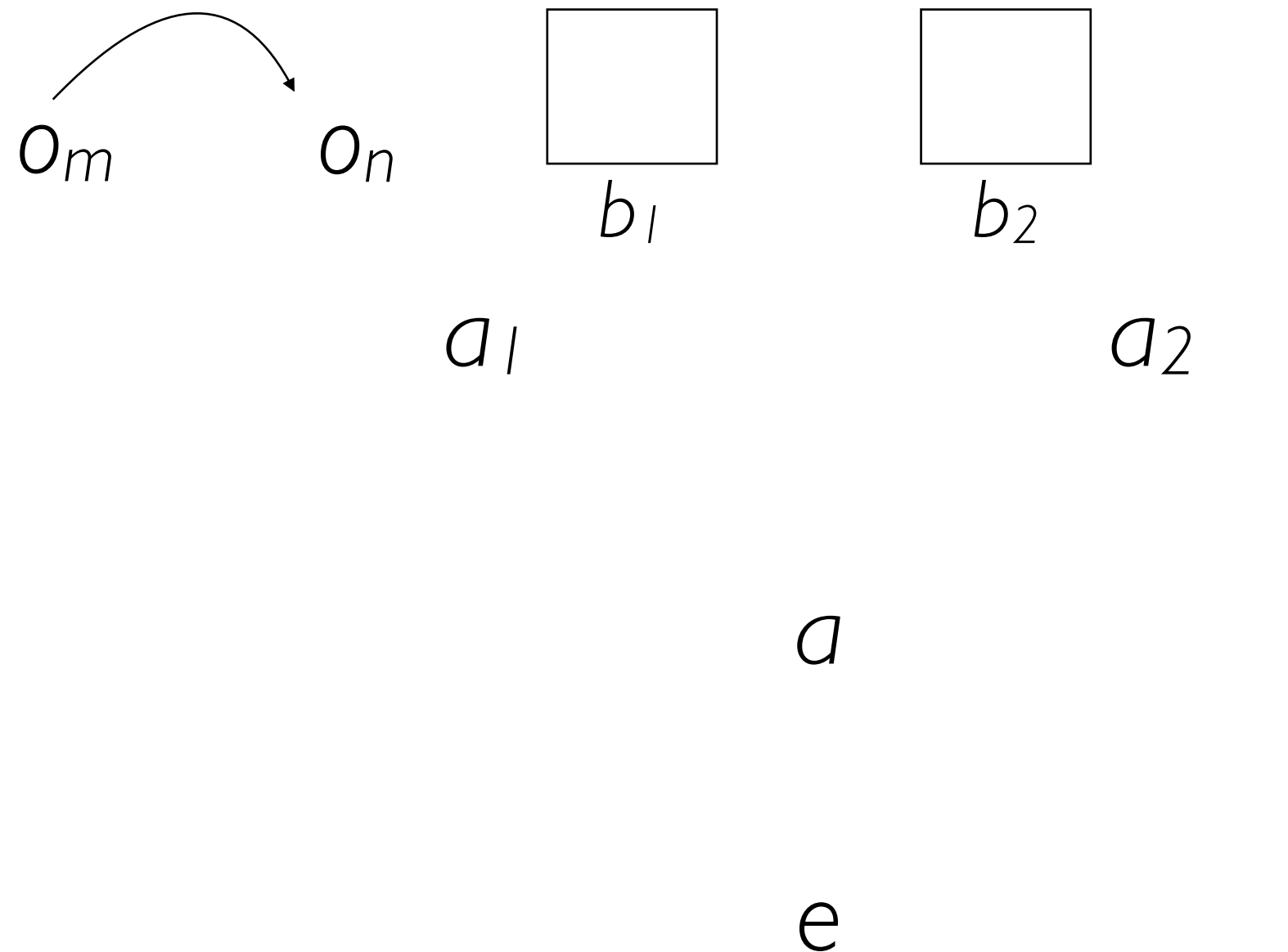
Framework for FBT₁

(six timepoints)



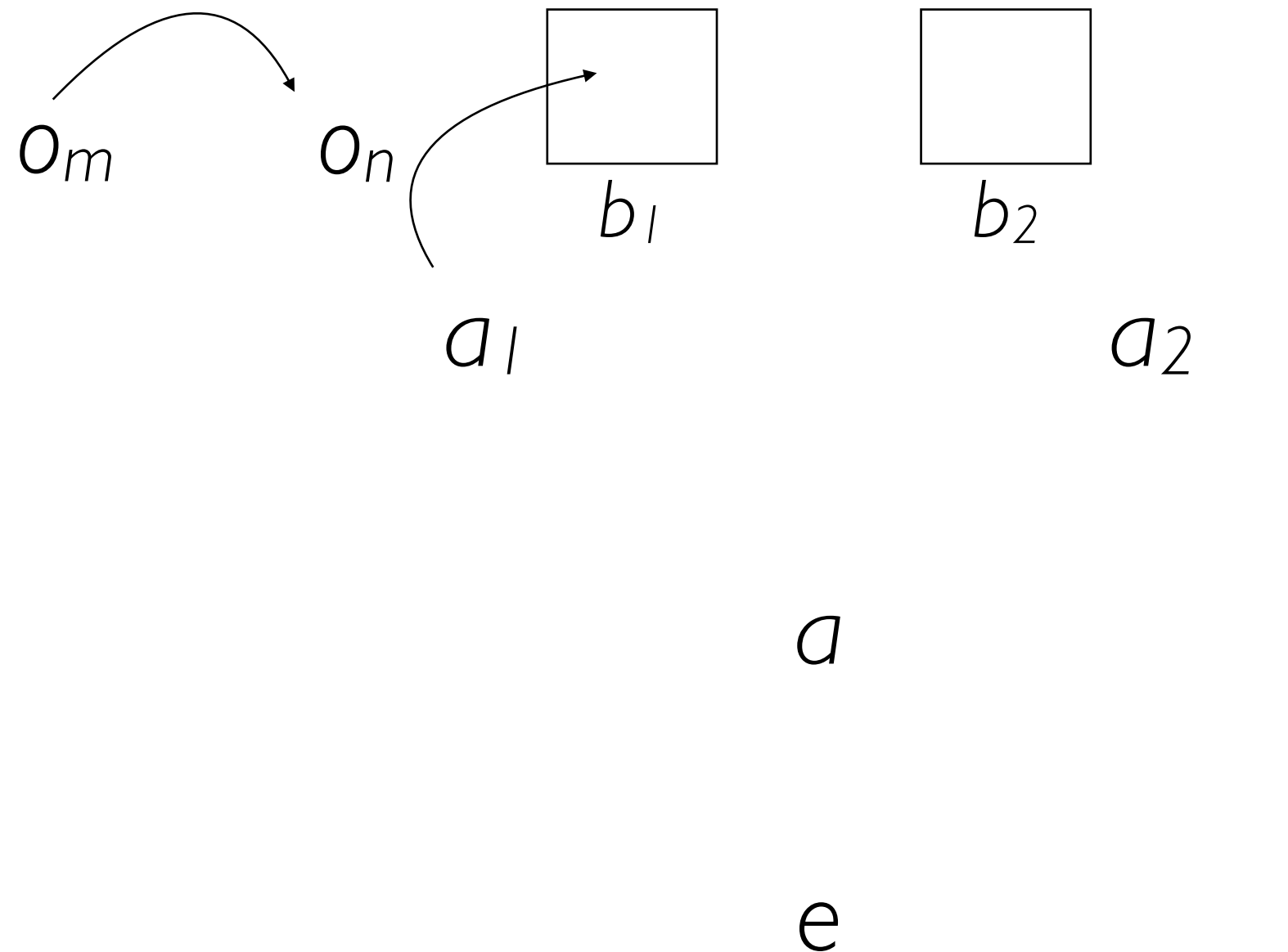
Framework for FBT₁

(six timepoints)



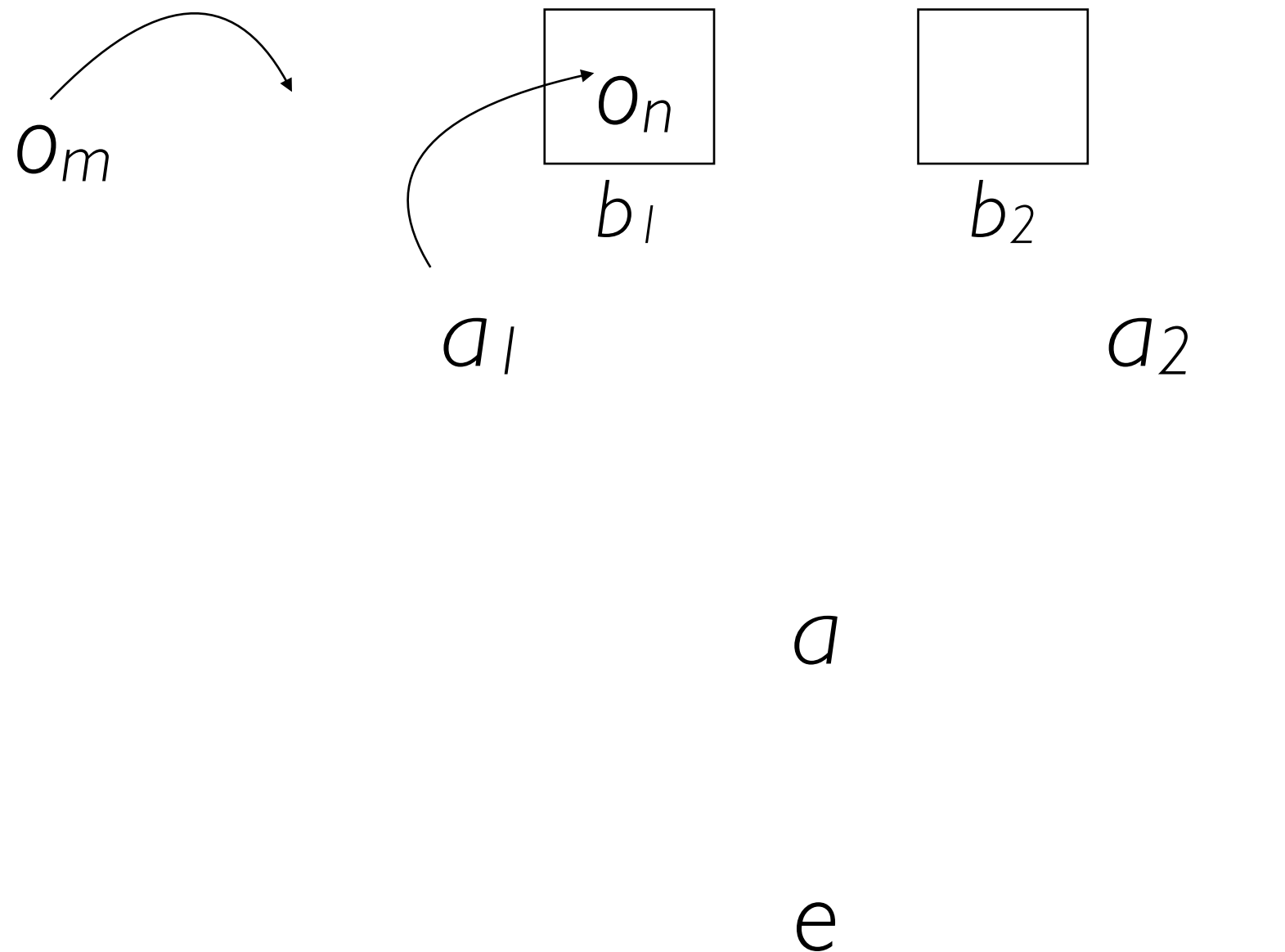
Framework for FBT₁

(six timepoints)



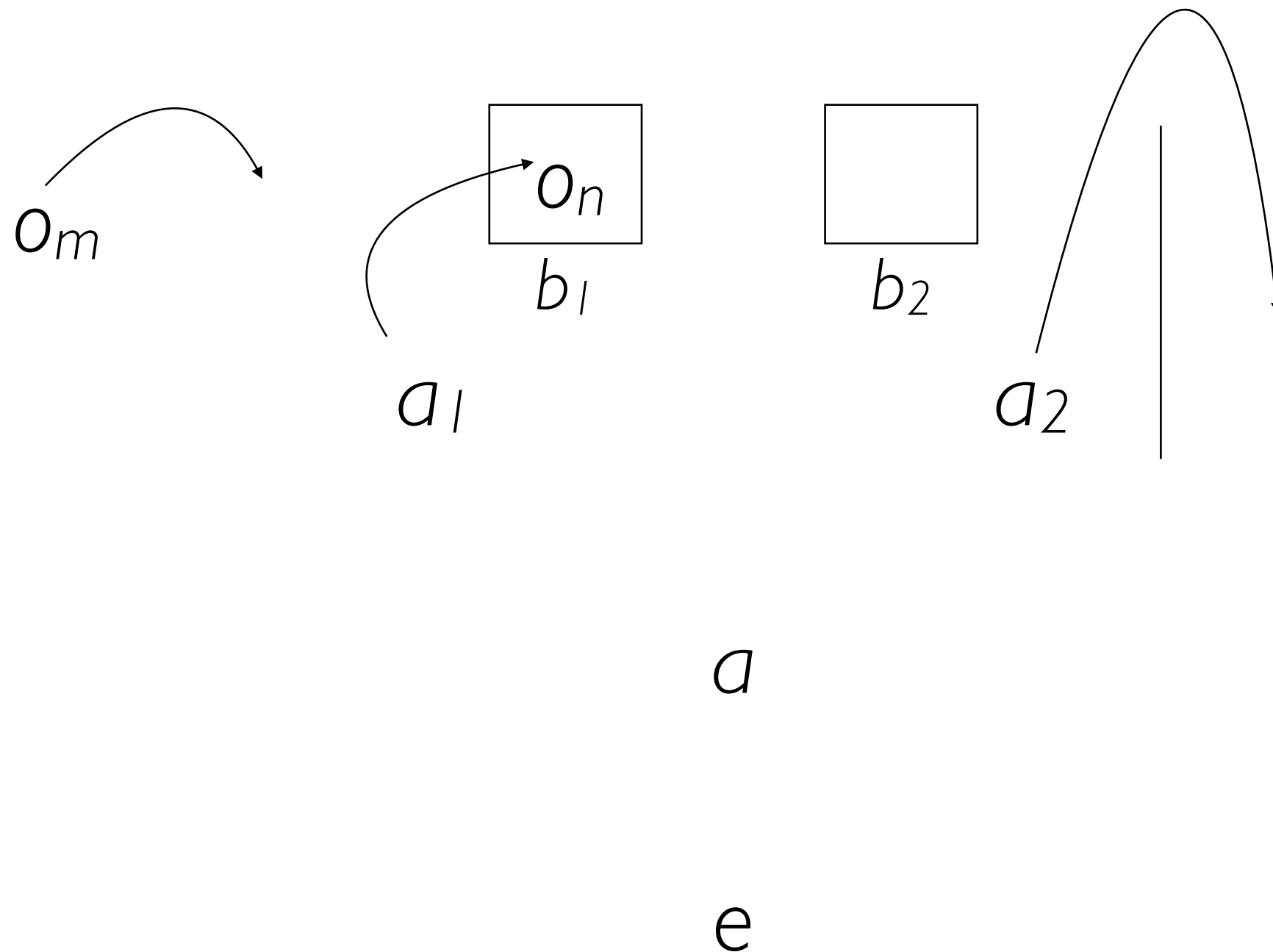
Framework for FBT₁

(six timepoints)



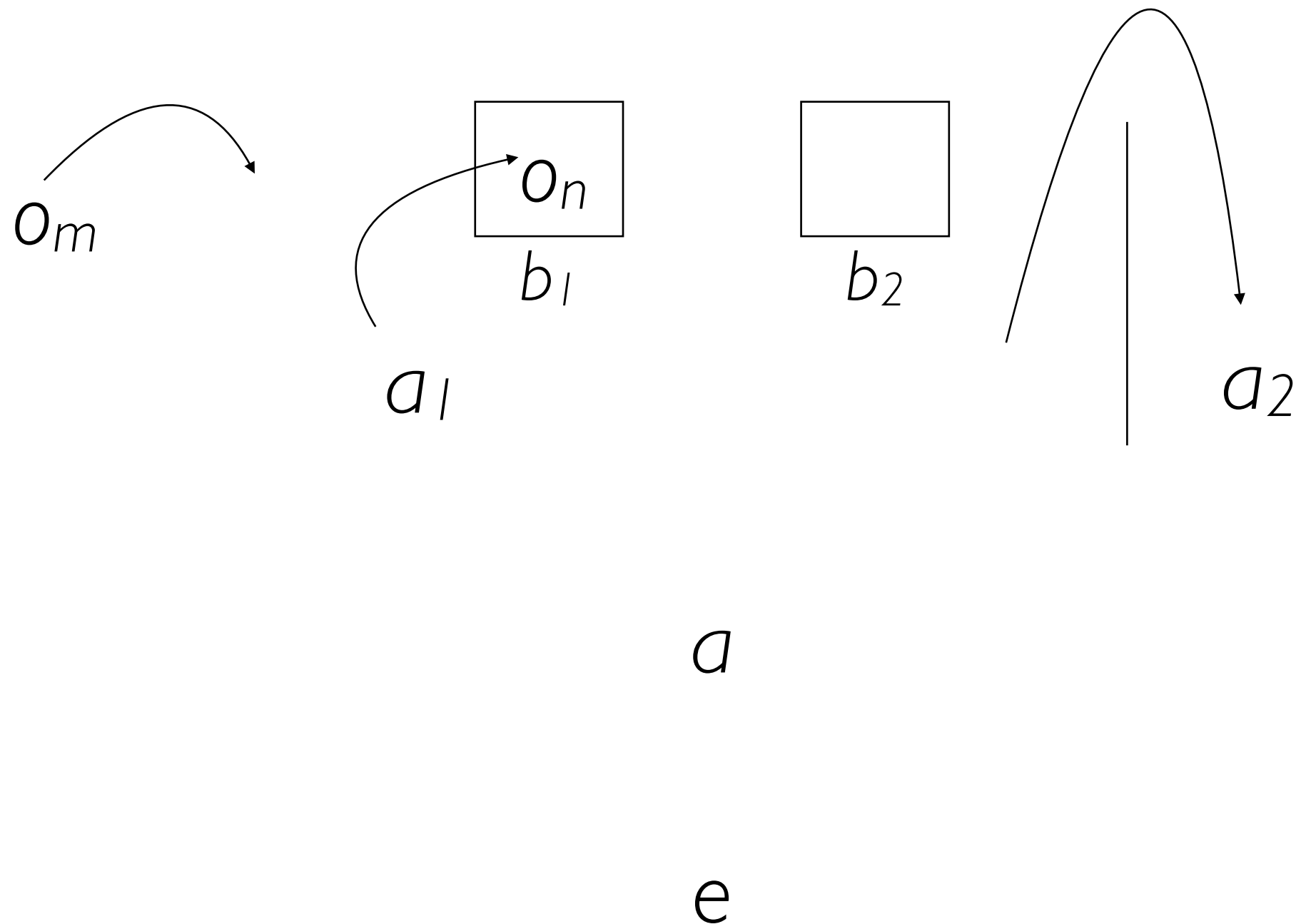
Framework for FBT₁

(six timepoints)



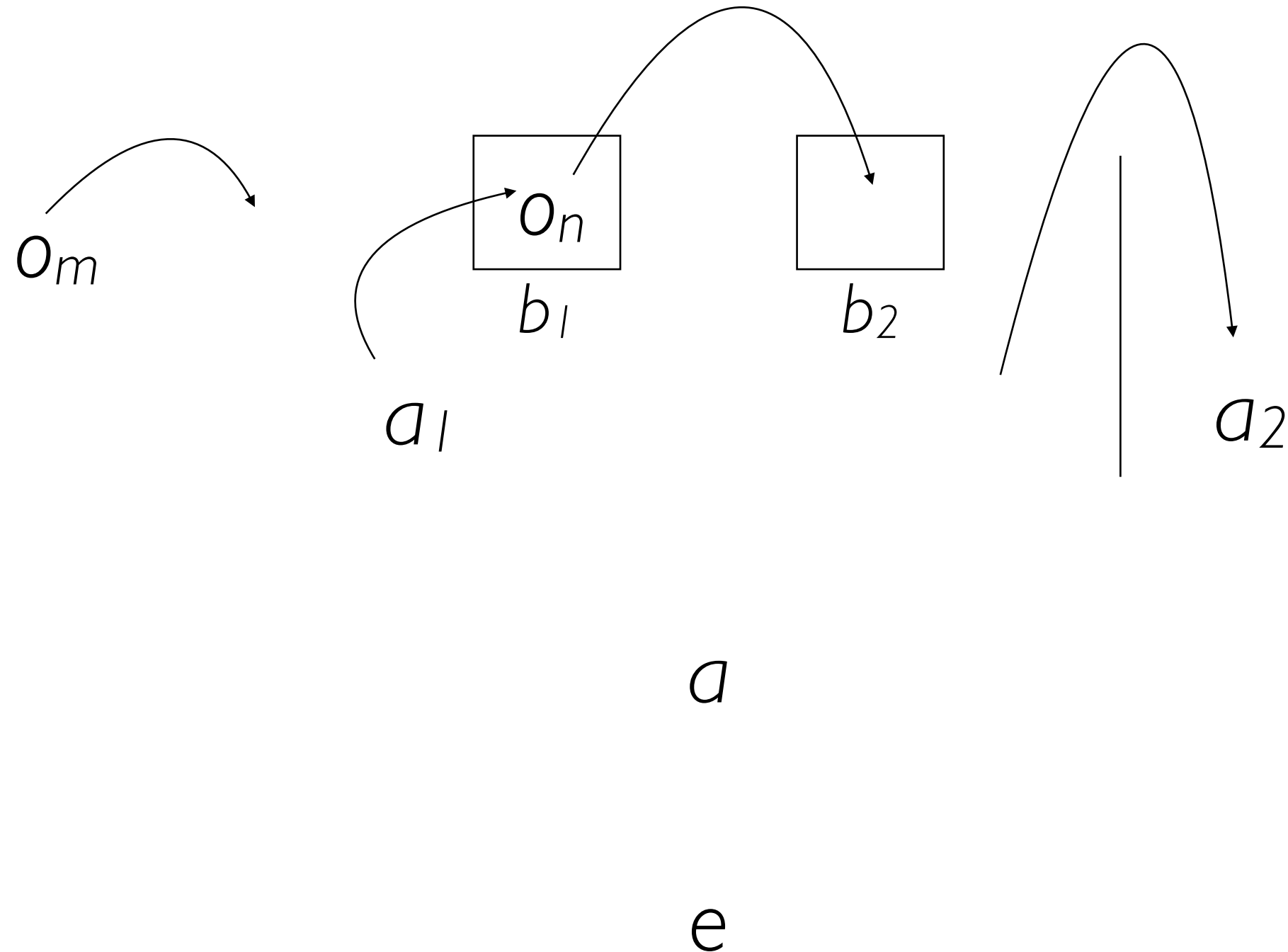
Framework for FBT₁

(six timepoints)



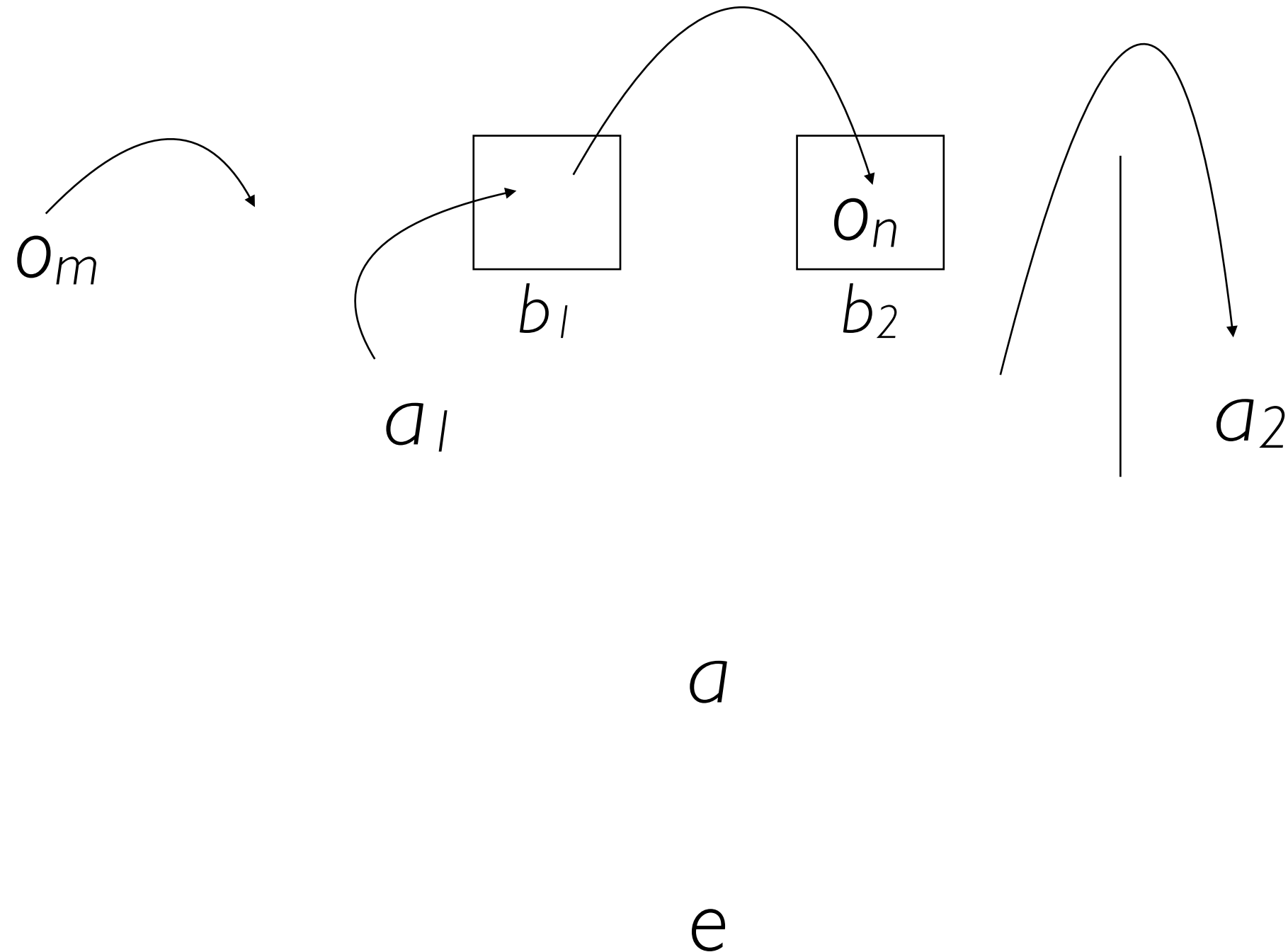
Framework for FBT₁

(six timepoints)



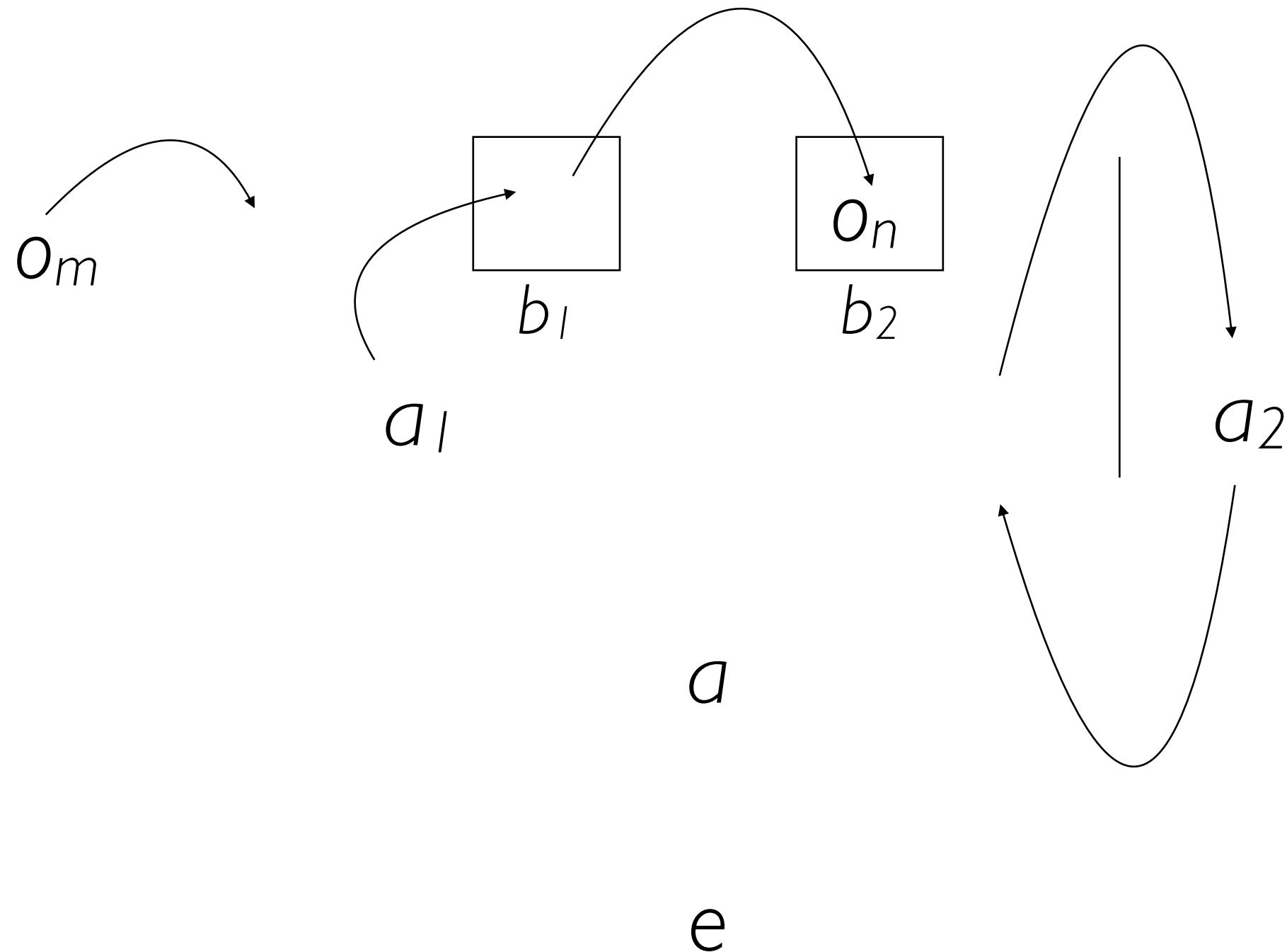
Framework for FBT₁

(six timepoints)



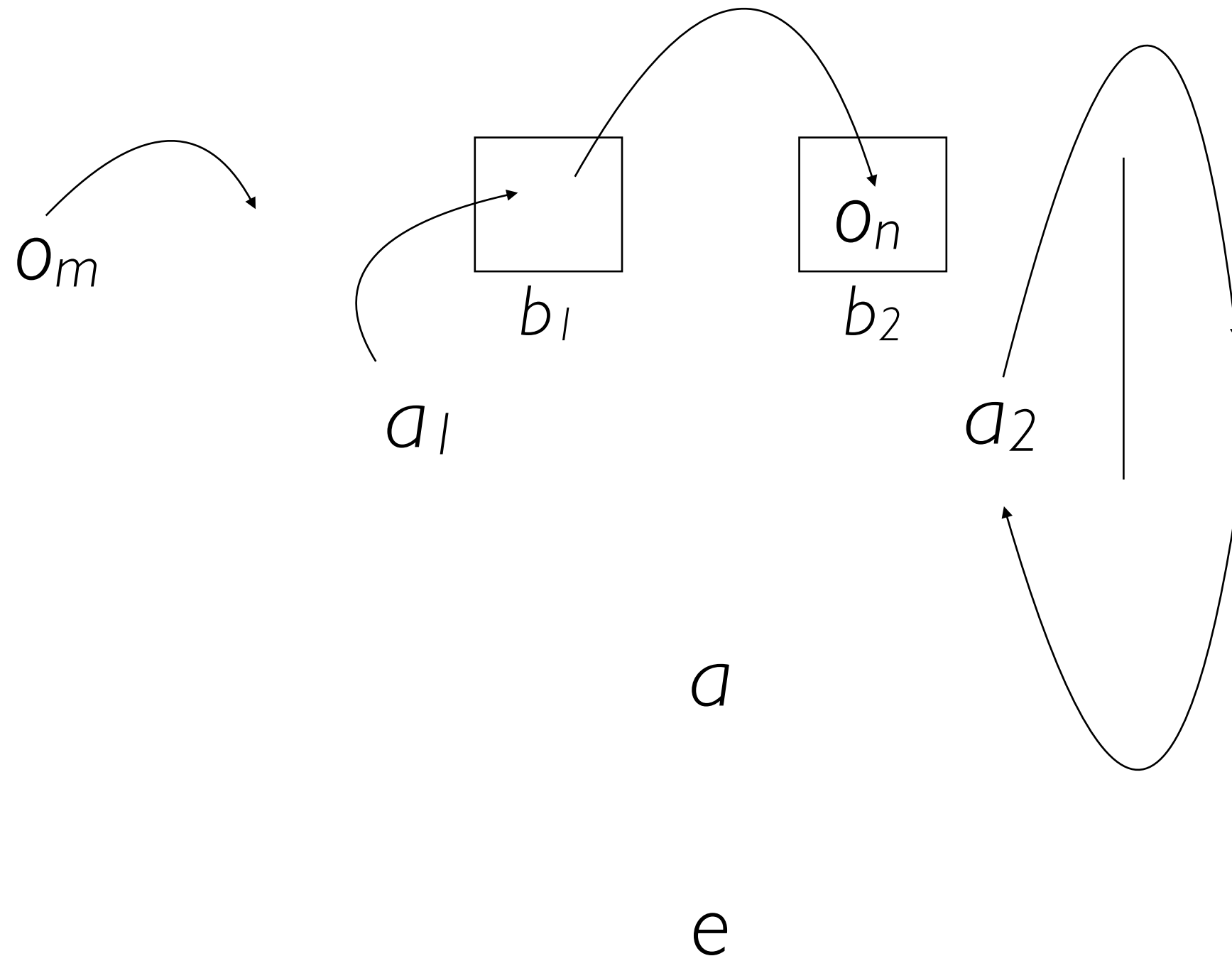
Framework for FBT₁

(six timepoints)



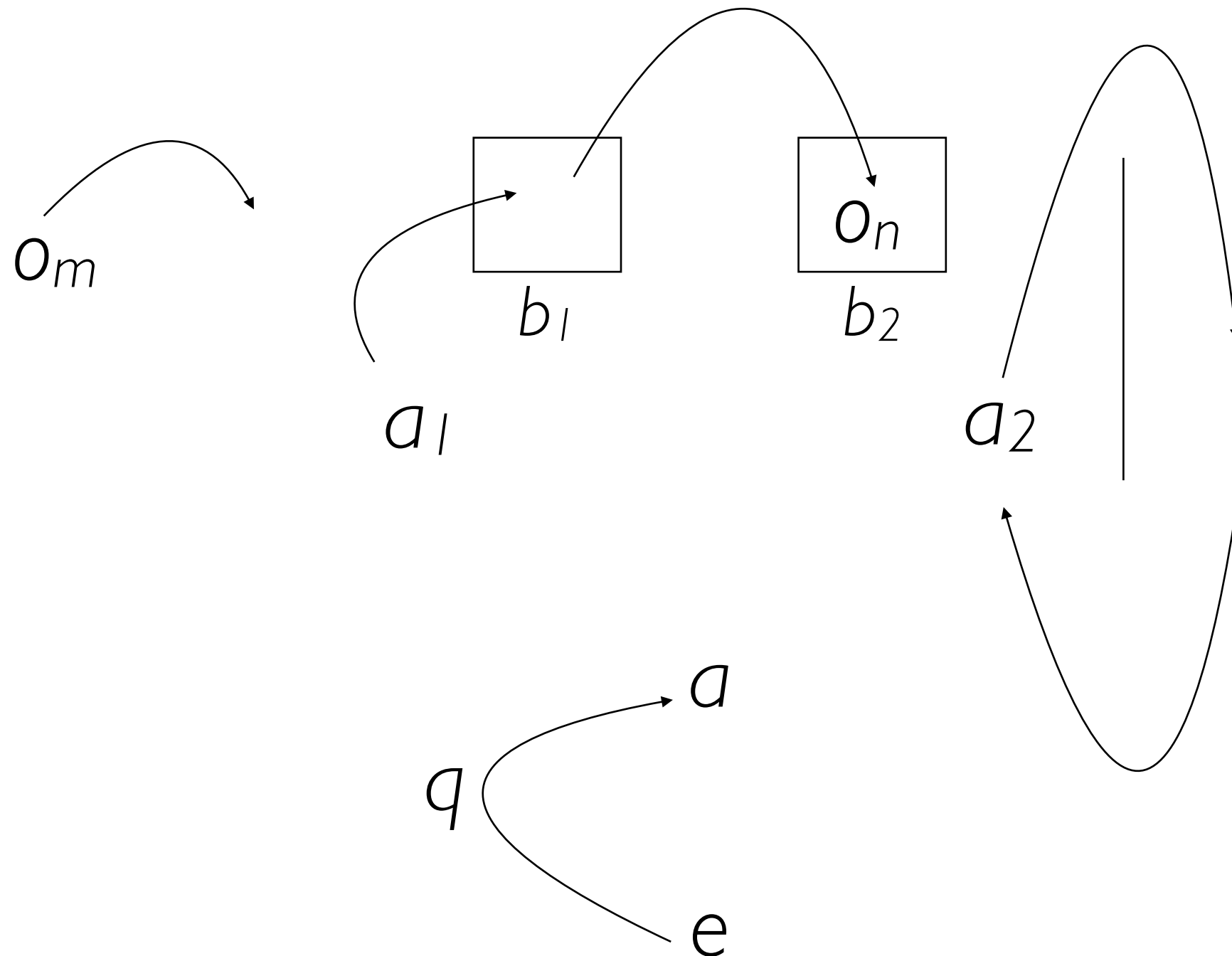
Framework for FBT₁

(six timepoints)



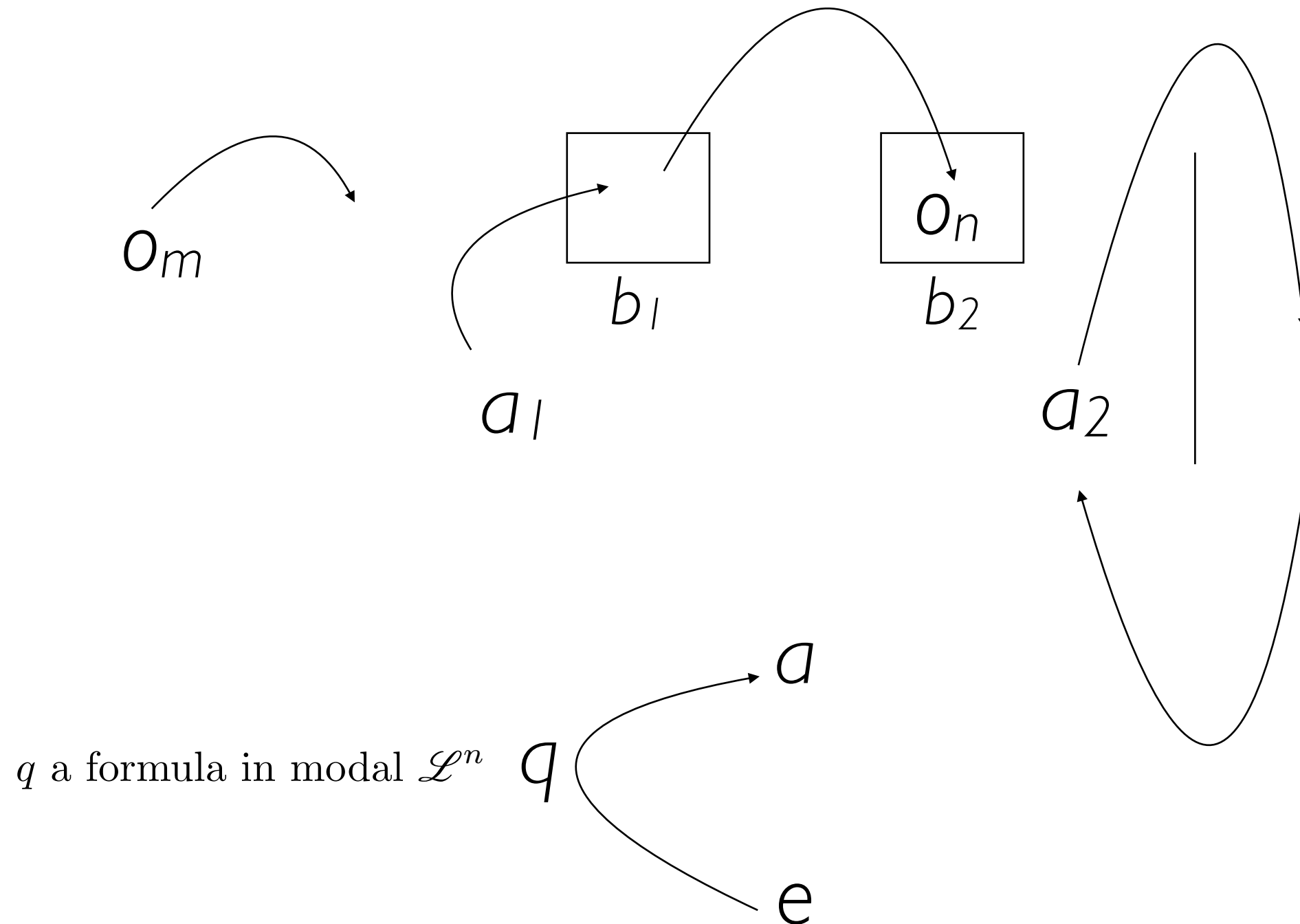
Framework for FBT₁

(six timepoints)



Framework for FBT^1_1

(six timepoints)



Done, a Decade Ago, Formally & Implementation/Simulation

Arkoudas, K. & Bringsjord, S.
(2009) “Propositional
Attitudes and Causation”
*International Journal of Software
and Informatics* **3.1**: 47–65.

http://kryten.mm.rpi.edu/PRICAI_w_sequentcalc_041709.pdf

Propositional attitudes and causation

Konstantine Arkoudas and Selmer Bringsjord

Cognitive Science and Computer Science Departments, RPI
arkouk@rpi.edu, brings@rpi.edu

Abstract. Predicting and explaining the behavior of others in terms of mental states is indispensable for everyday life. It will be equally important for artificial agents. We present an inference system for representing and reasoning about mental states, and use it to provide a formal analysis of the false-belief task. The system allows for the representation of information about events, causation, and perceptual, doxastic, and epistemic states (vision, belief, and knowledge), incorporating ideas from the event calculus and multi-agent epistemic logic. Unlike previous AI formalisms, our focus here is on mechanized proofs and proof programmability, not on metamathematical results. Reasoning is performed via relatively cognitively plausible inference rules, and a degree of automation is achieved by general-purpose inference methods and by a syntactic embedding of the system in first-order logic.

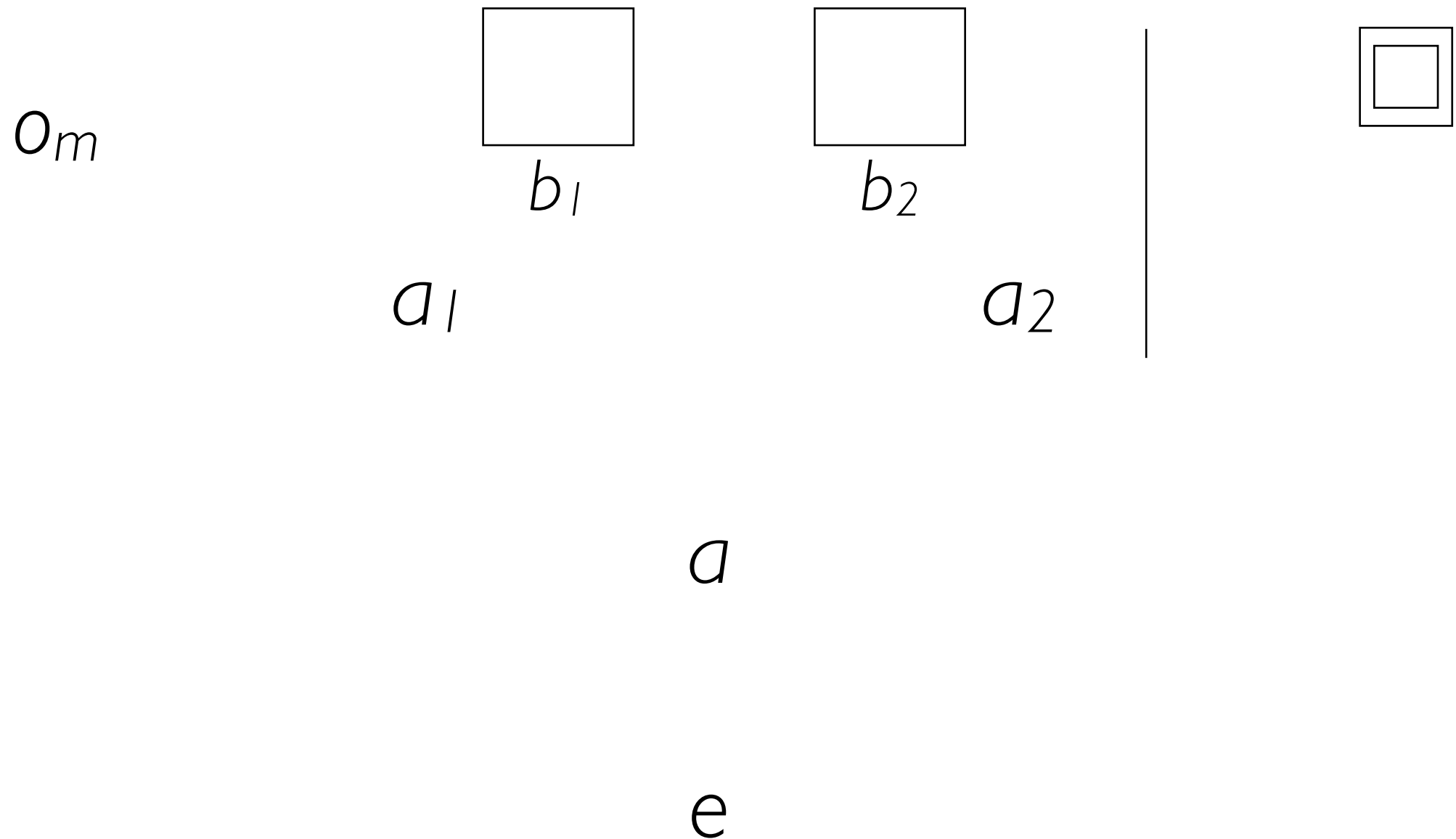
1 Introduction

Interpreting the behavior of other people is indispensable for everyday life. It is something that we do constantly, on a daily basis, and it helps us not only to make sense of human behavior, but also to predict it and—to a certain extent—to control it. How exactly do we manage that? That is not currently known, but many have argued that the ability to ascribe mental states to others and to reason about such mental states is a key component of our capacity to understand human behavior. In particular, all social transactions, from engaging in commerce and negotiating to making jokes and empathizing with other people's pain or joy, appear to require at least a rudimentary grasp of common-sense psychology (CSP), i.e., a large body of truisms such as the following: When an agent a (1) wants to achieve a certain state of affairs p , and (2) believes that some action c can bring about p , and (3) a knows how to carry out c ; then, ceteris paribus,¹ a will carry out c ; when a sees that p , a knows that p ; when a fears that p and a discovers that p is the case, a is disappointed; and so on.

Artificial agents without a mastery of CSP would be severely handicapped in their interactions with humans. This could present problems not only for artificial agents trying to interpret human behavior, but also for artificial agents trying to interpret the behavior of one another. When a system exhibits a complex but rational behavior, and detailed knowledge of its internal structure is not

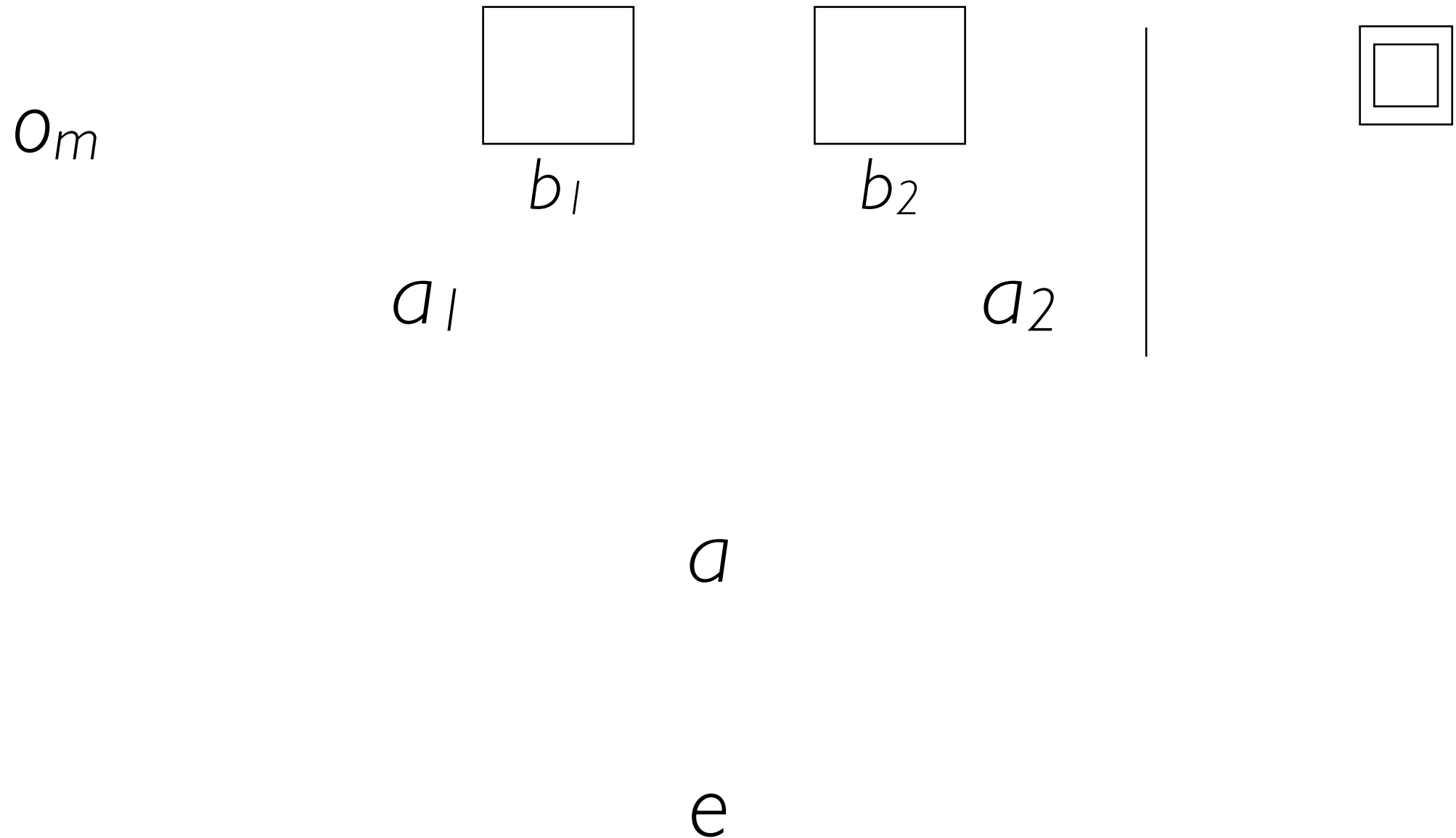
¹ Assuming that a is able to carry out c , that a has no conflicting desires that override his goal that p ; and so on.

Framework for FBT₂



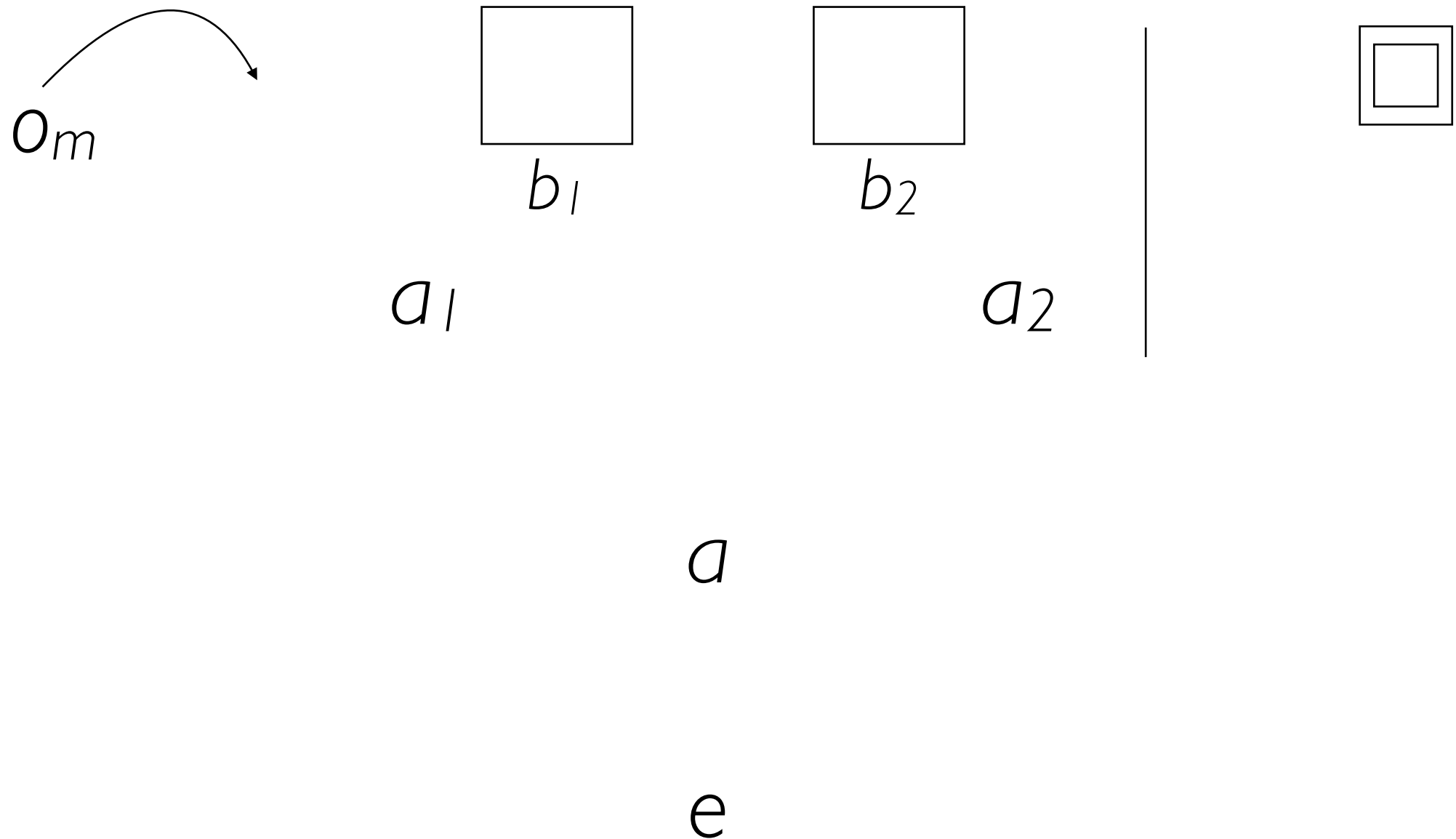
Framework for FBT₂

(seven timepoints)



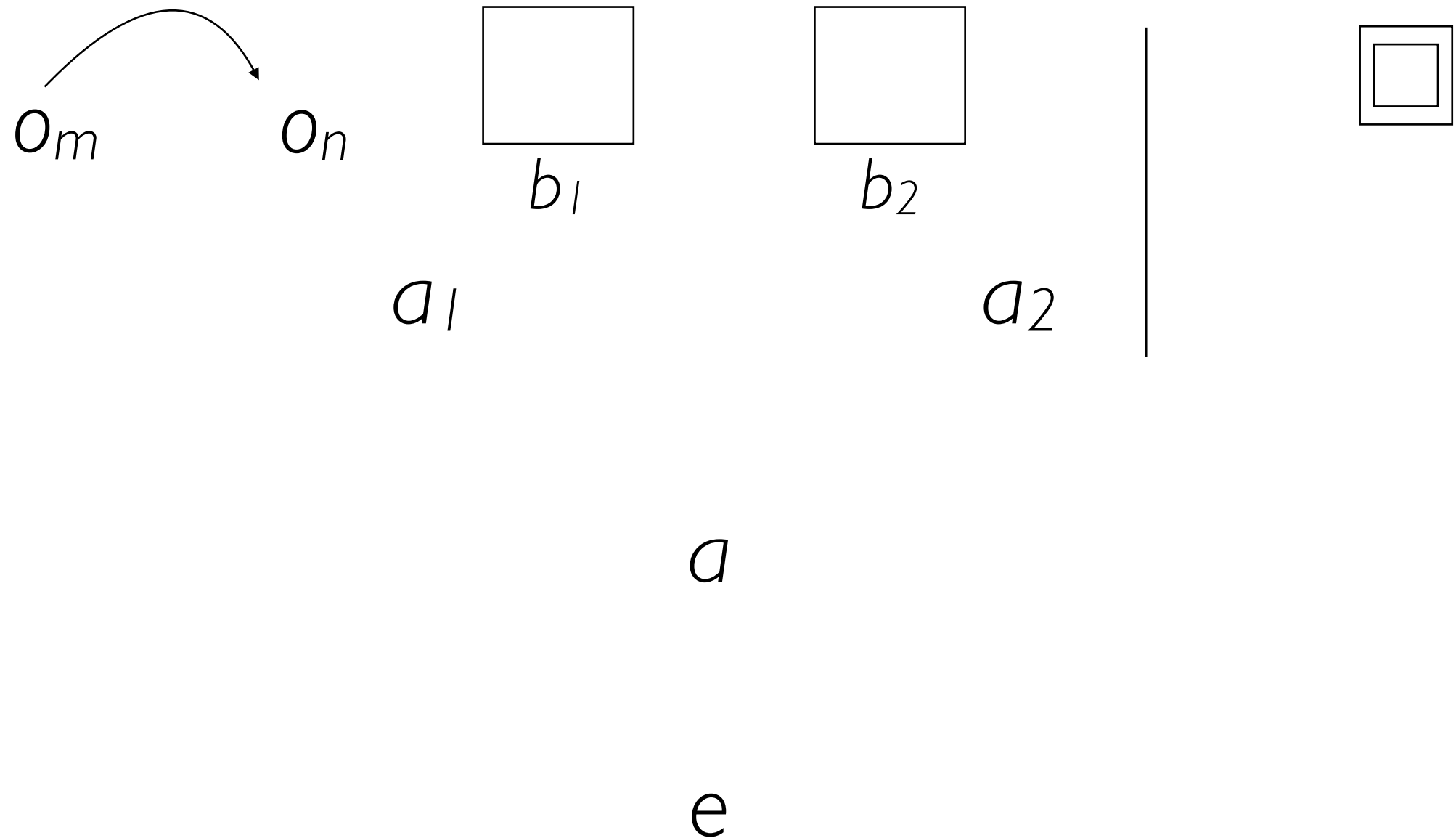
Framework for FBT^I_2

(seven timepoints)

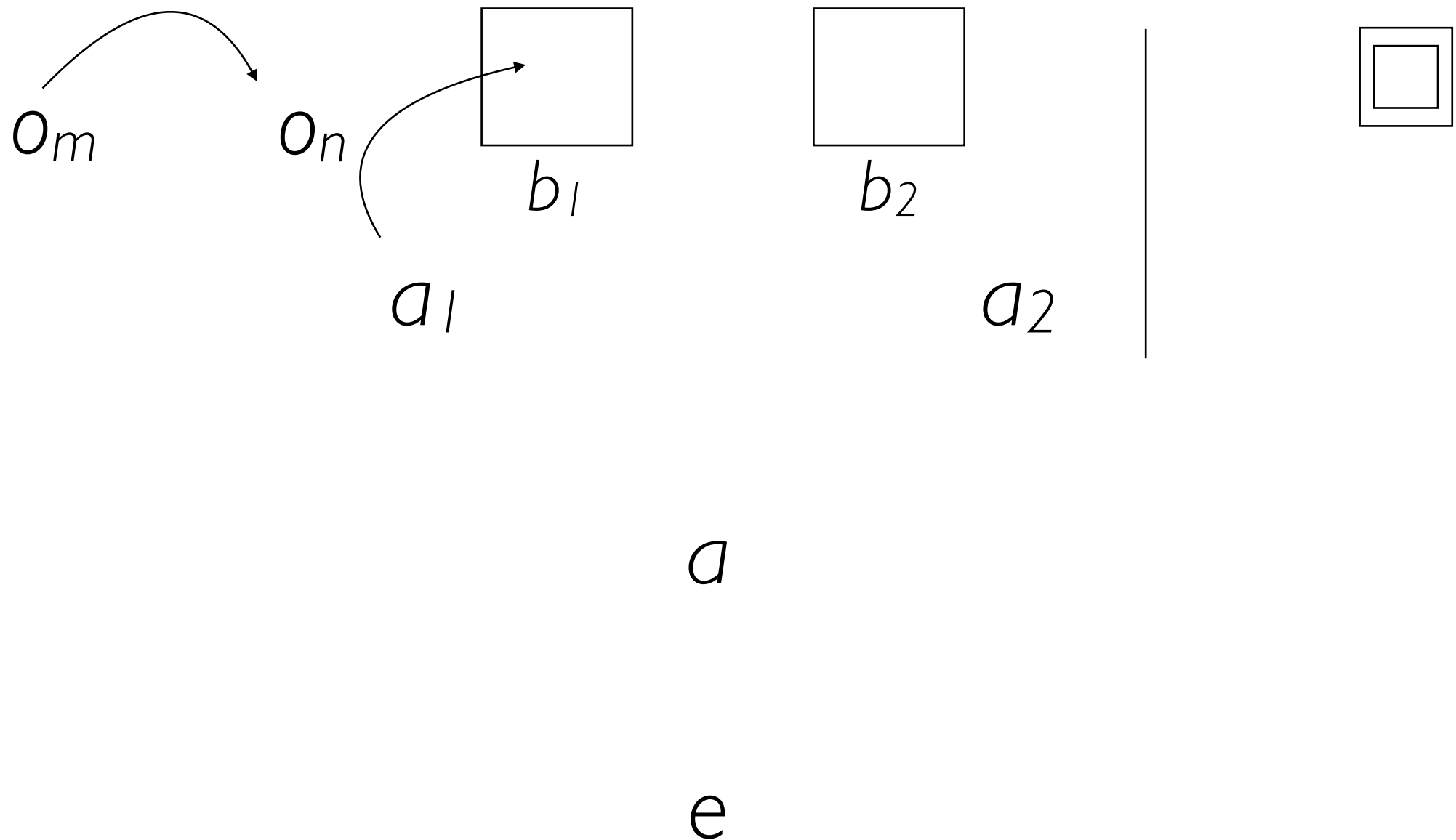


Framework for FBT^I_2

(seven timepoints)

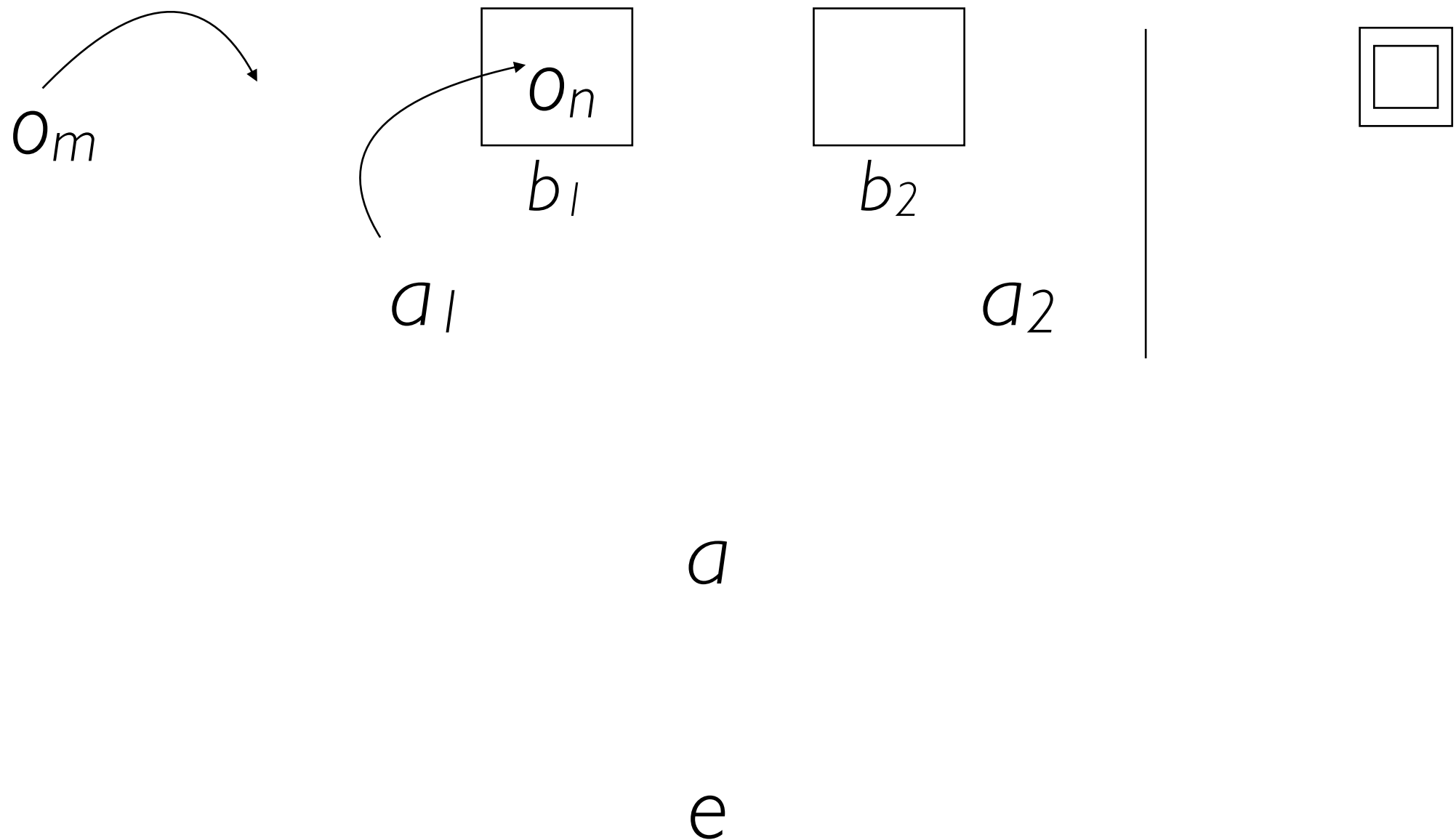


Framework for FBT₂ (seven timepoints)



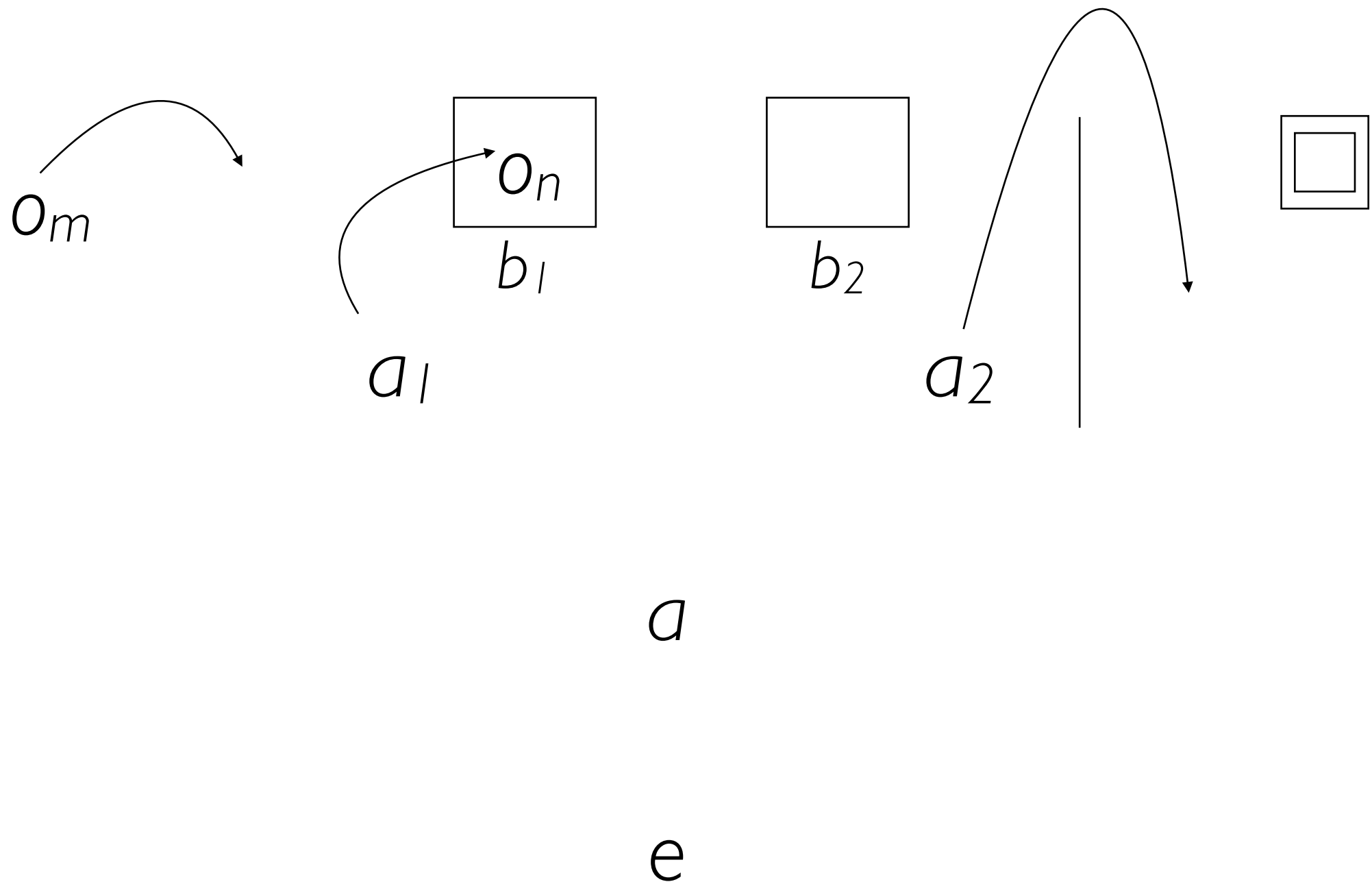
Framework for FBT^1_2

(seven timepoints)



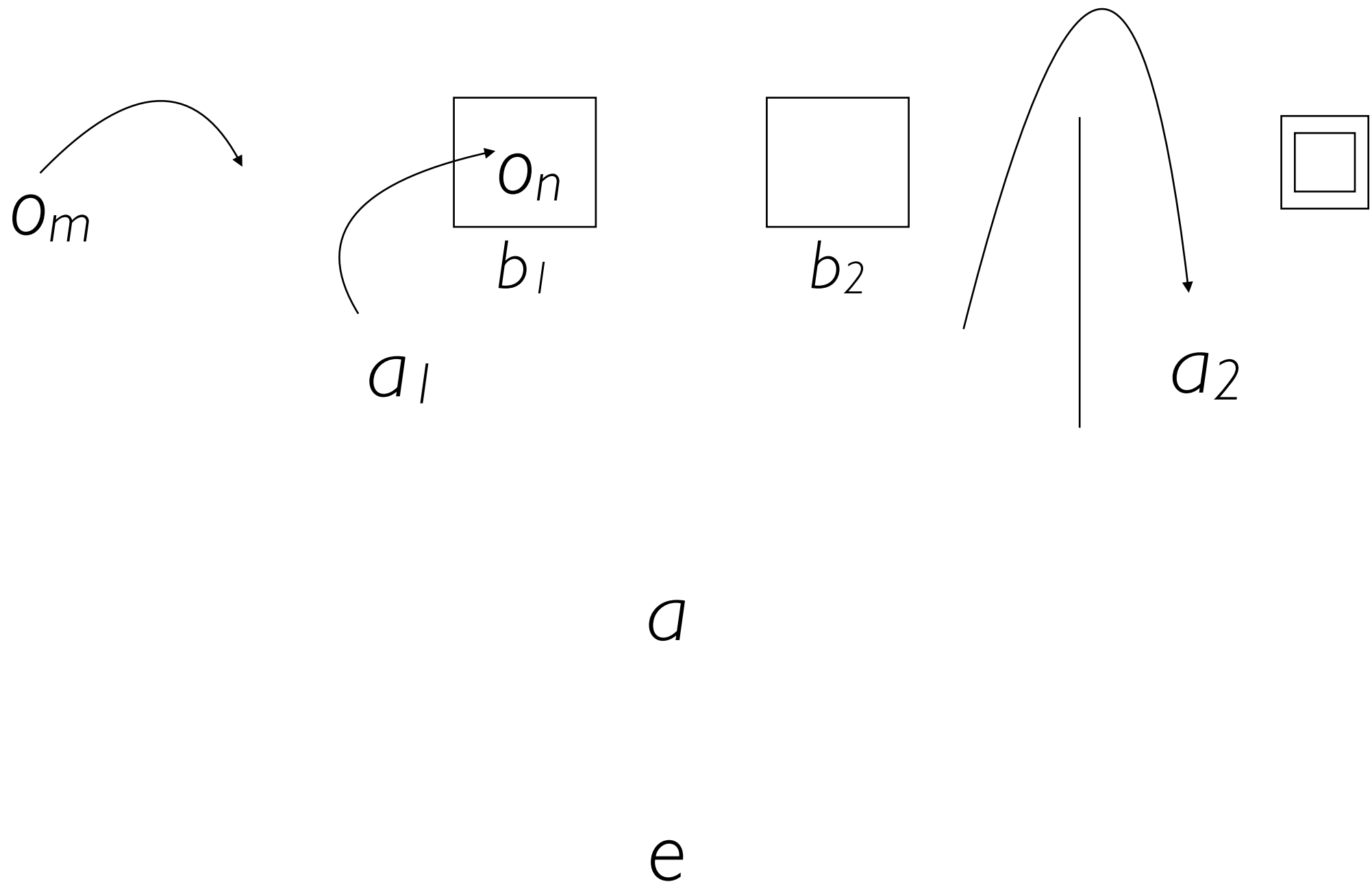
Framework for FBT^1_2

(seven timepoints)



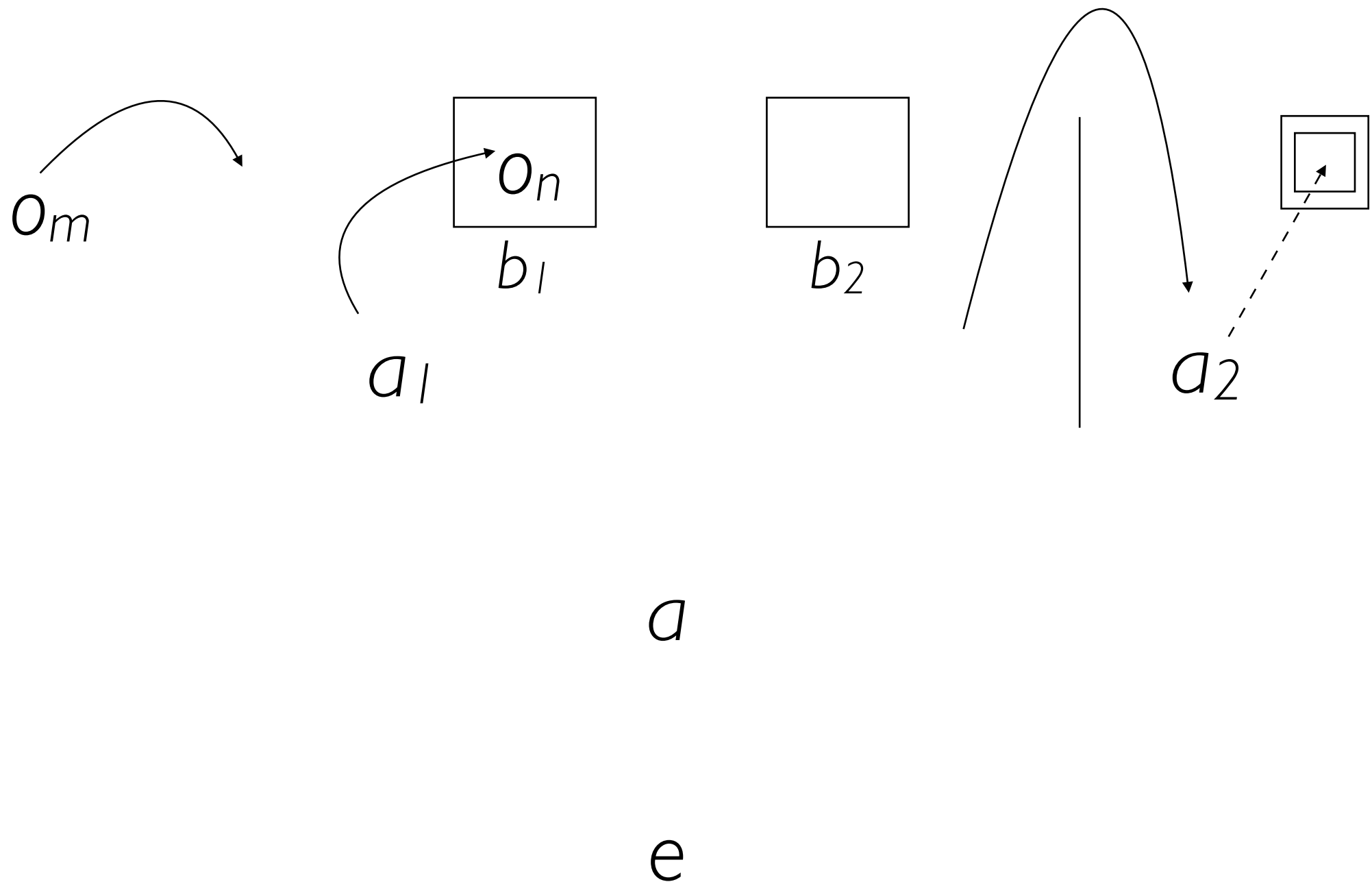
Framework for FBT^1_2

(seven timepoints)



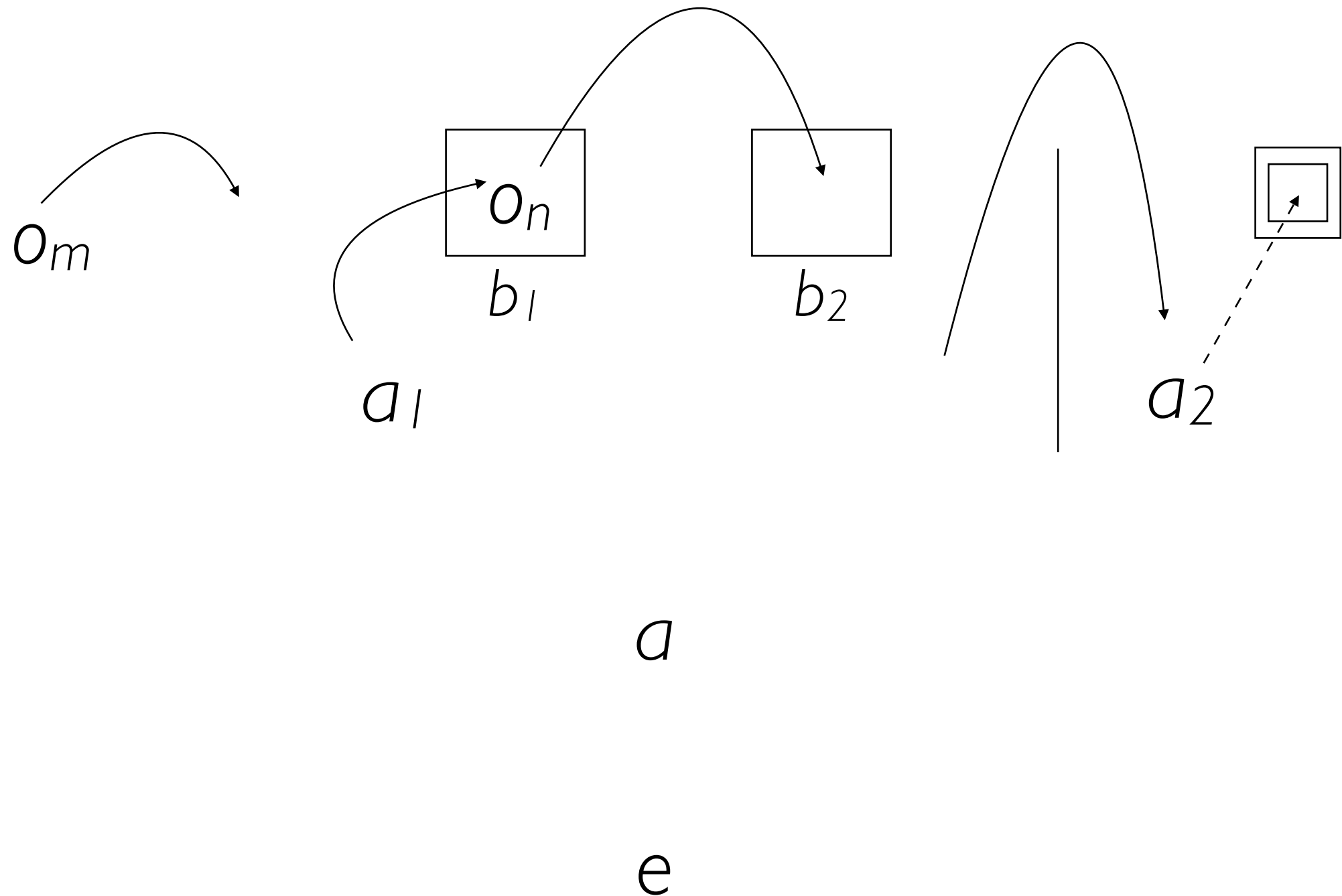
Framework for FBT^1_2

(seven timepoints)



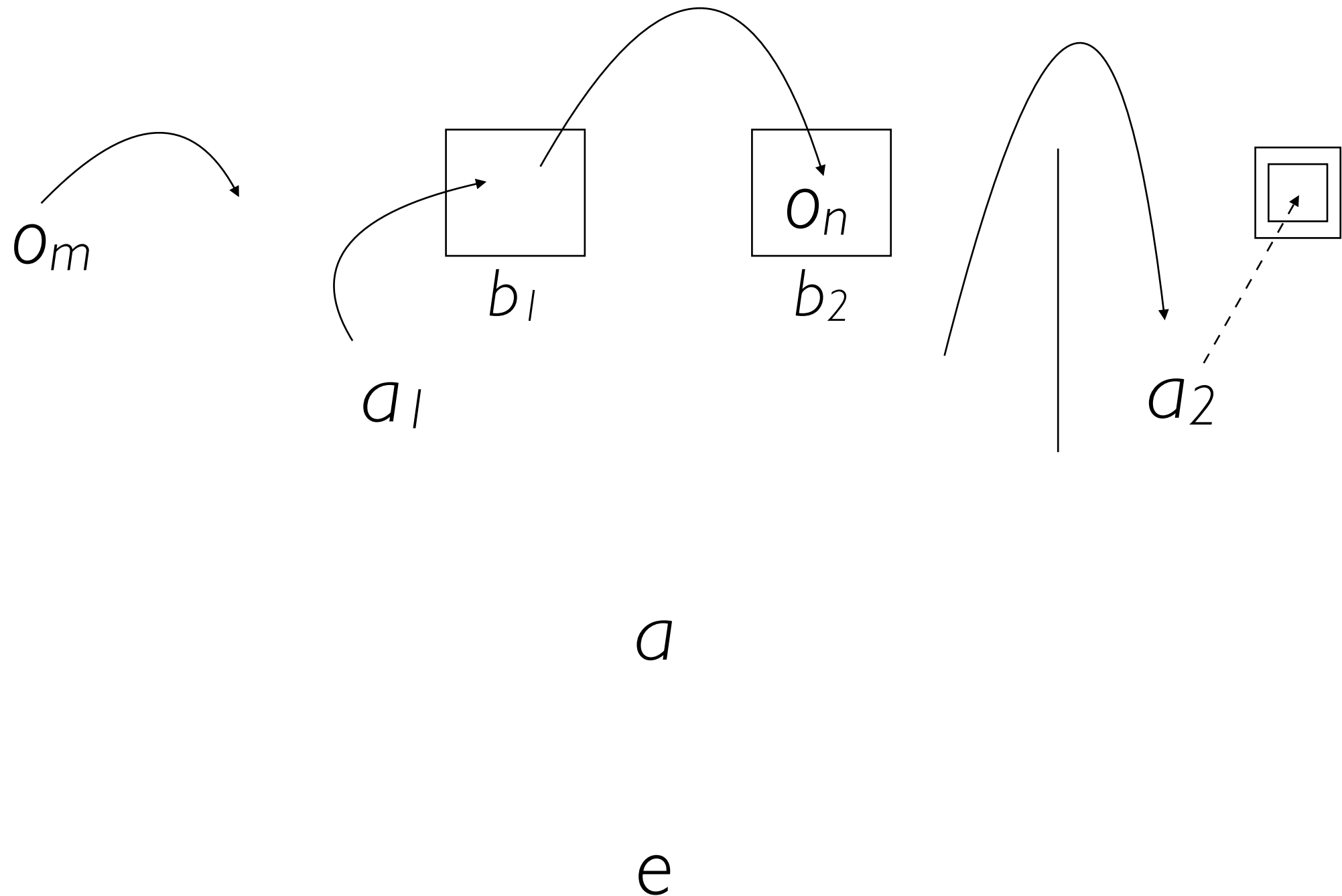
Framework for FBT^1_2

(seven timepoints)



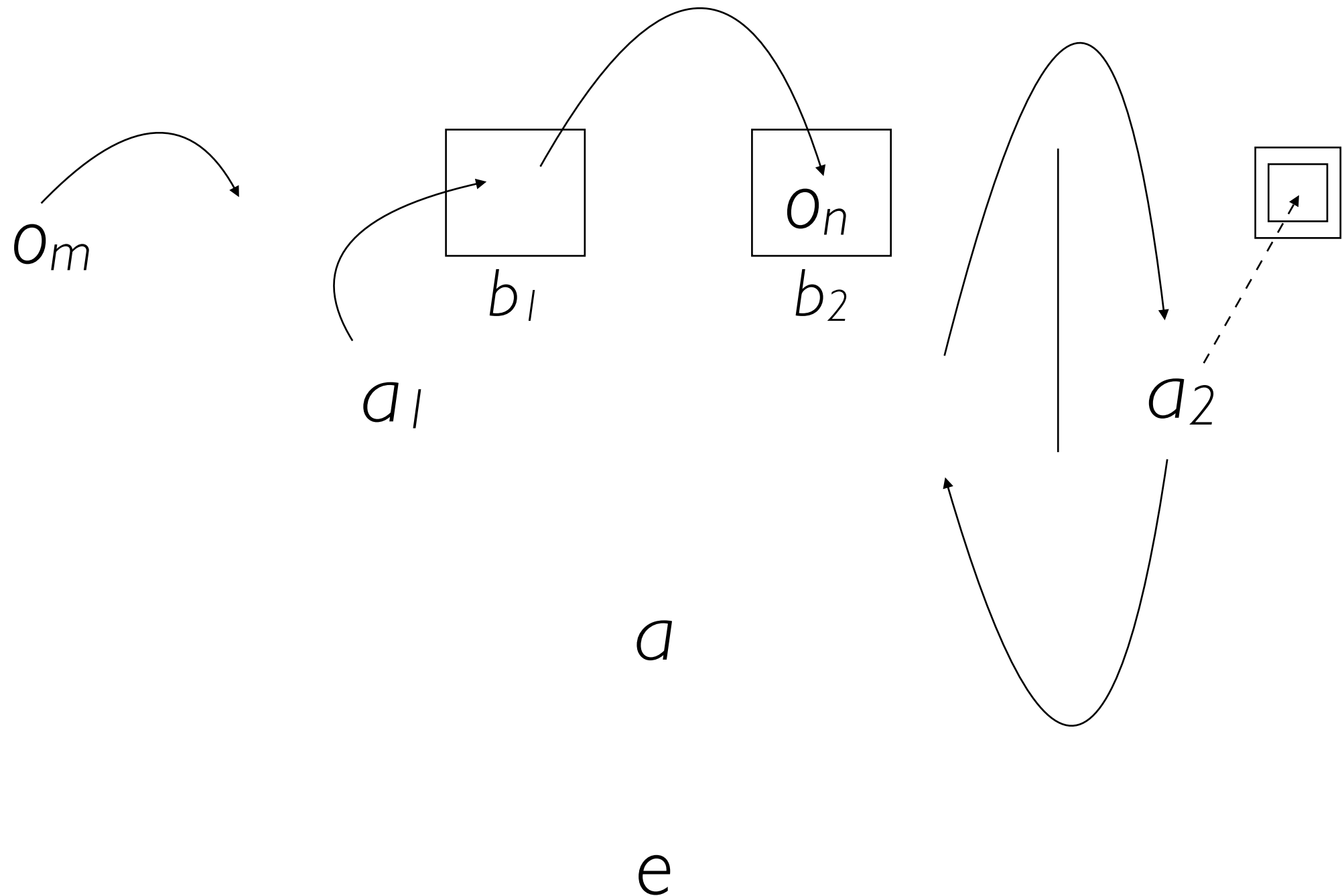
Framework for FBT^1_2

(seven timepoints)



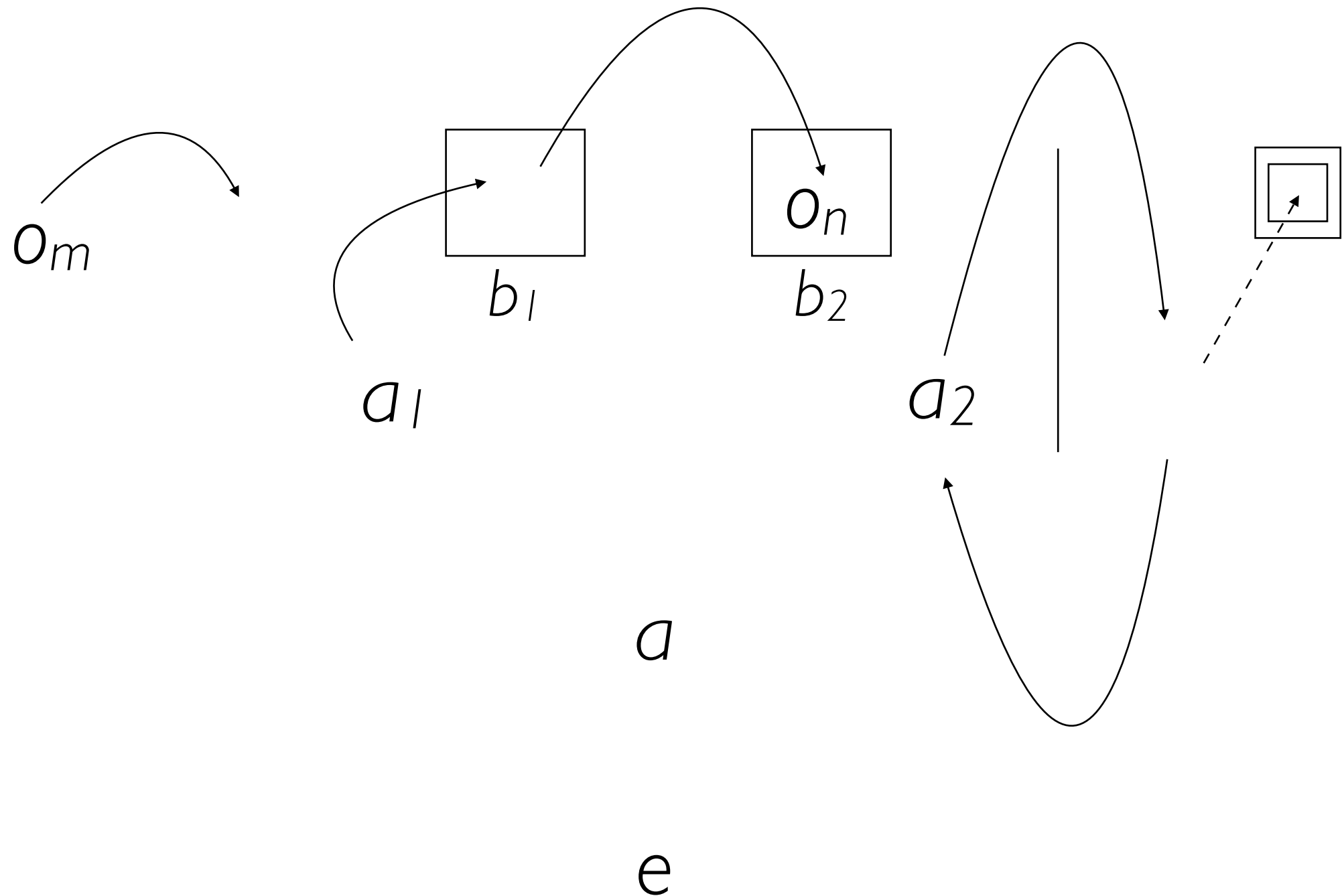
Framework for FBT^1_2

(seven timepoints)



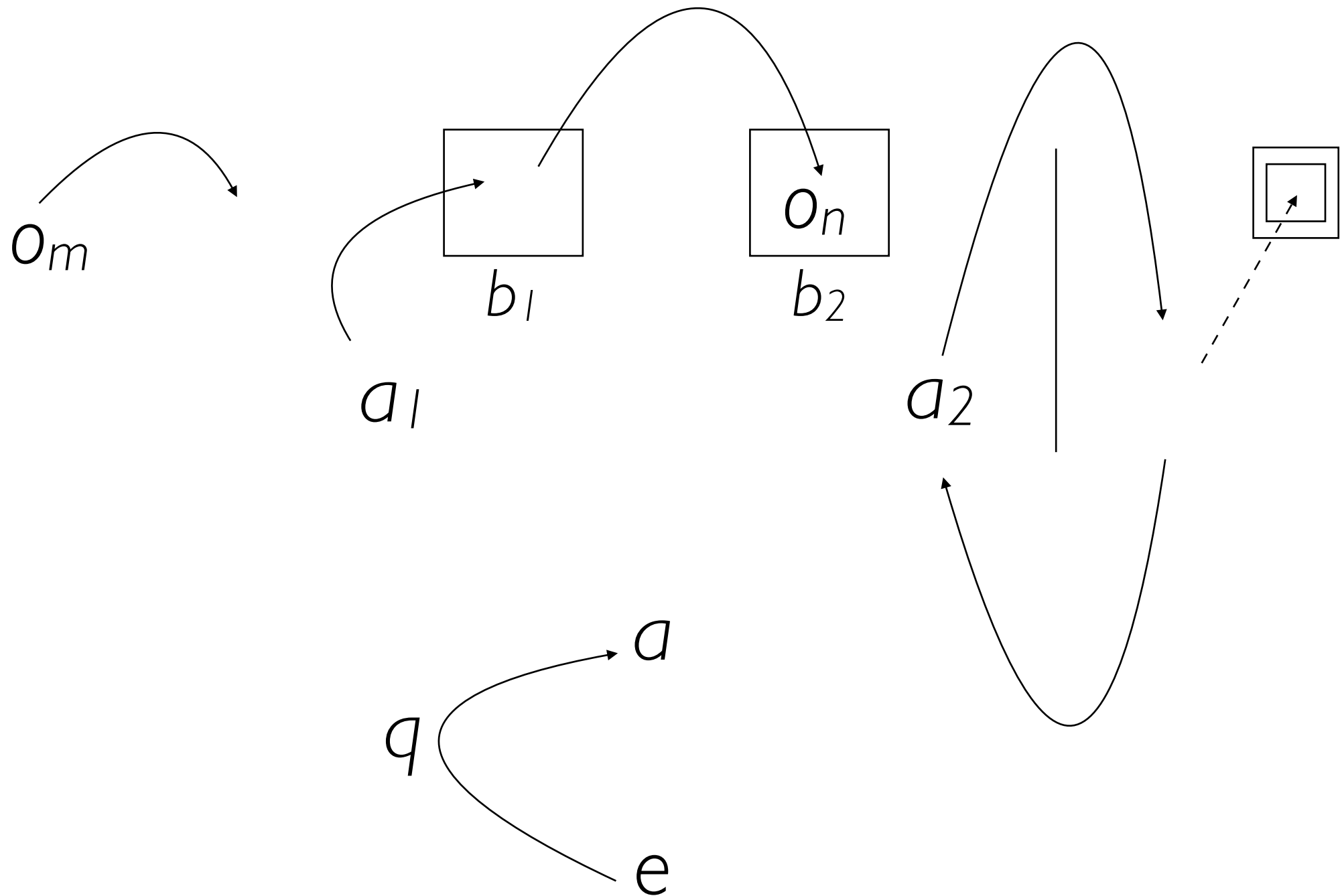
Framework for FBT^1_2

(seven timepoints)



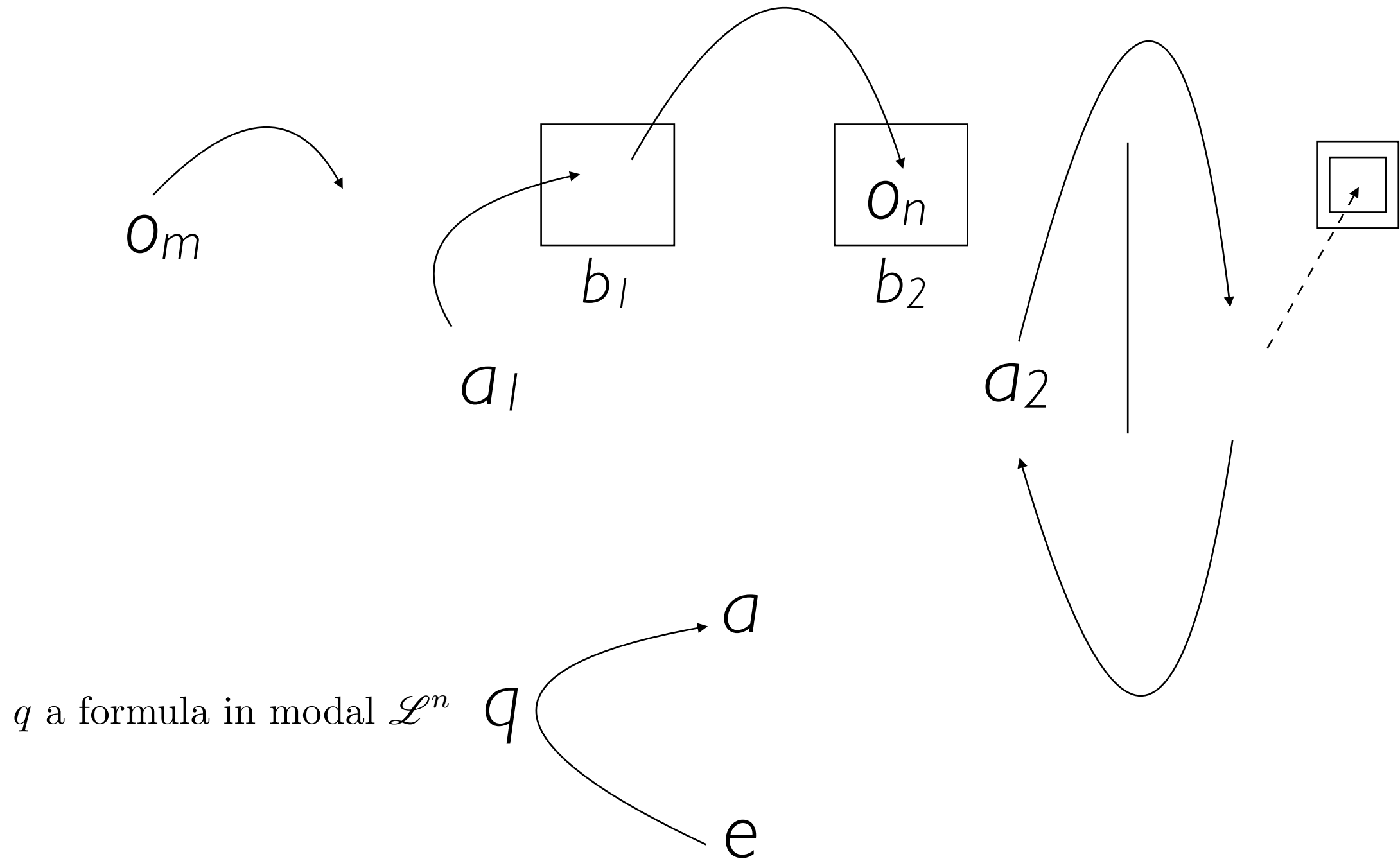
Framework for FBT^1_2

(seven timepoints)

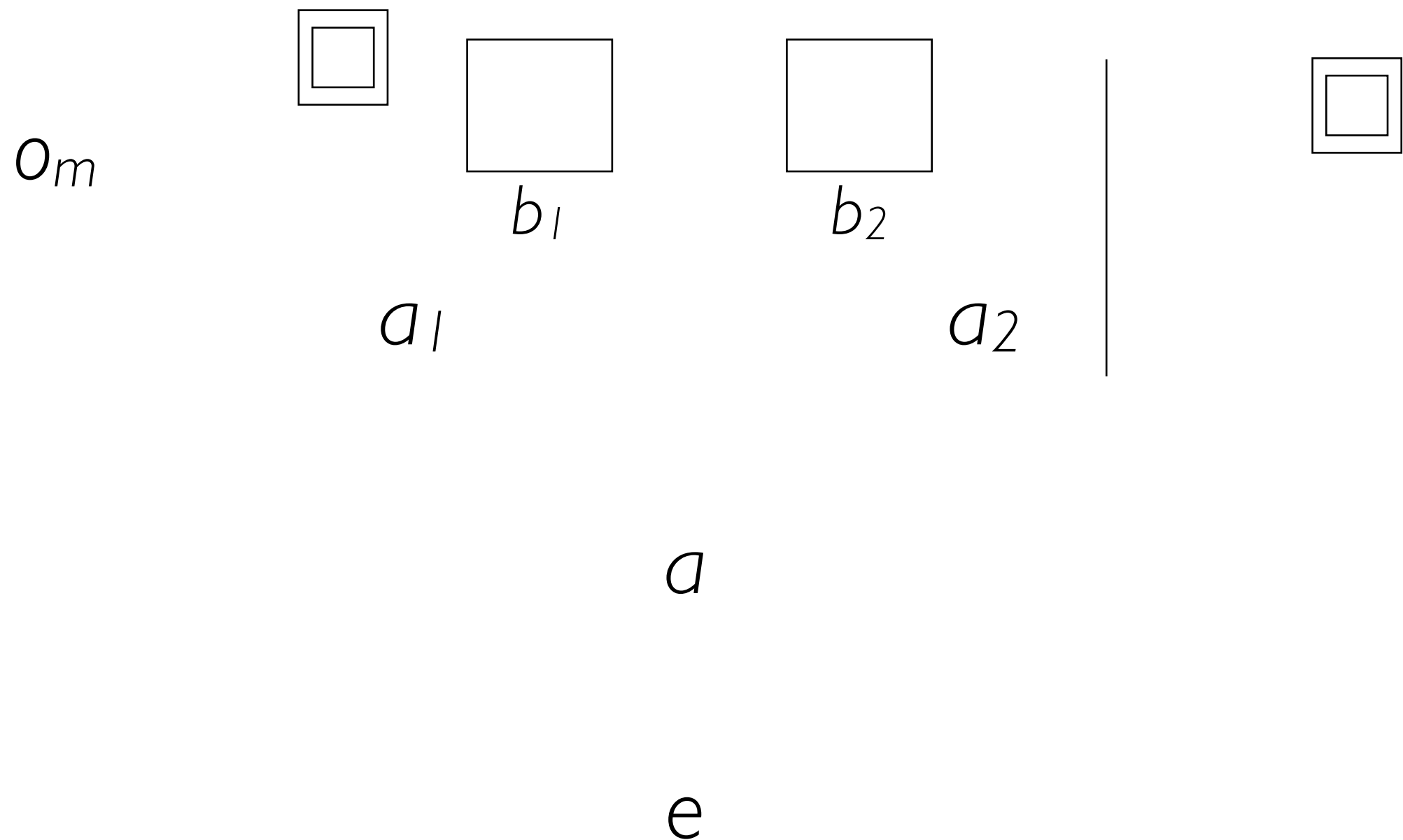


Framework for FBT^1_2

(seven timepoints)

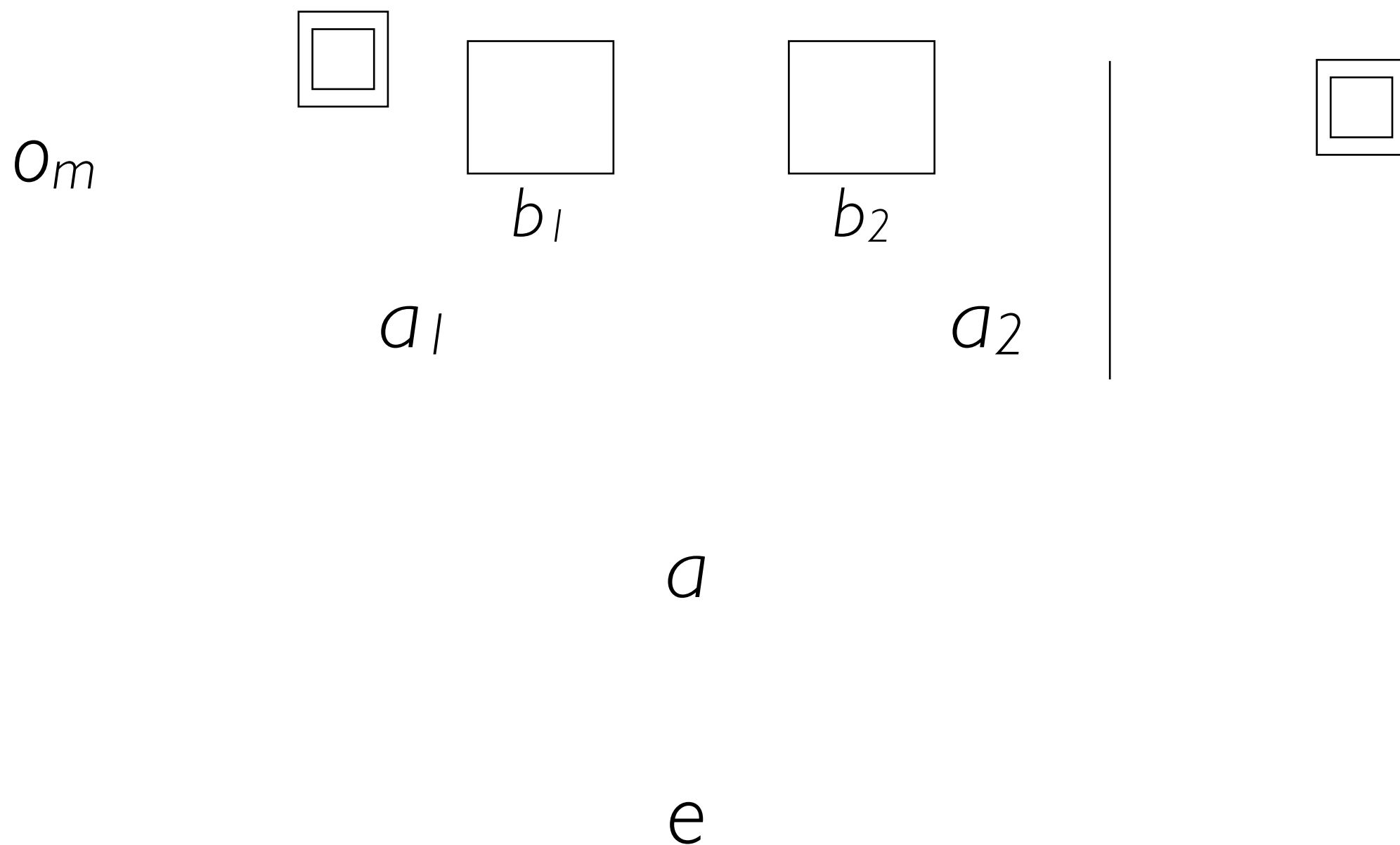


Framework for FBT^I_3



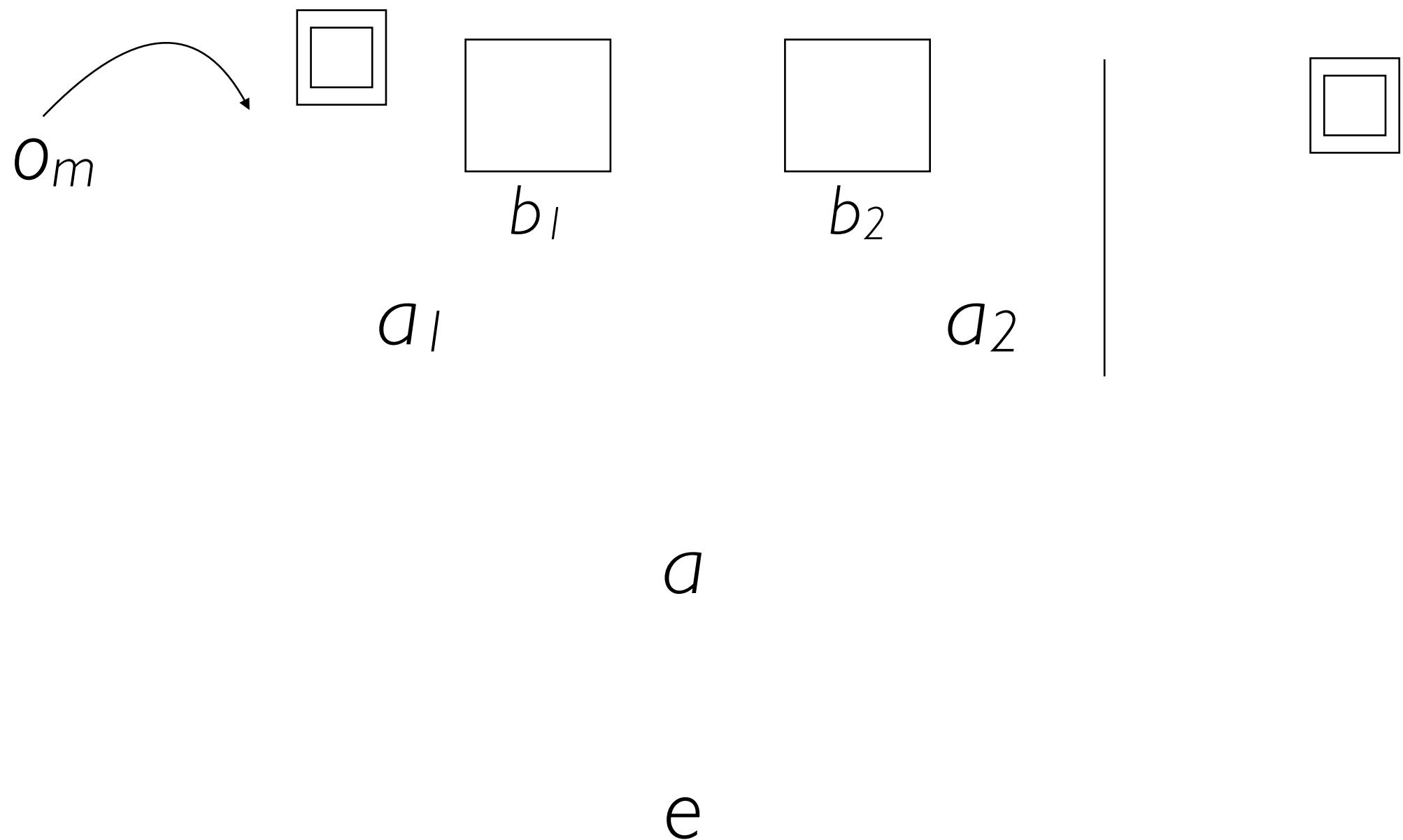
Framework for FBT^I_3

(eight timepoints)



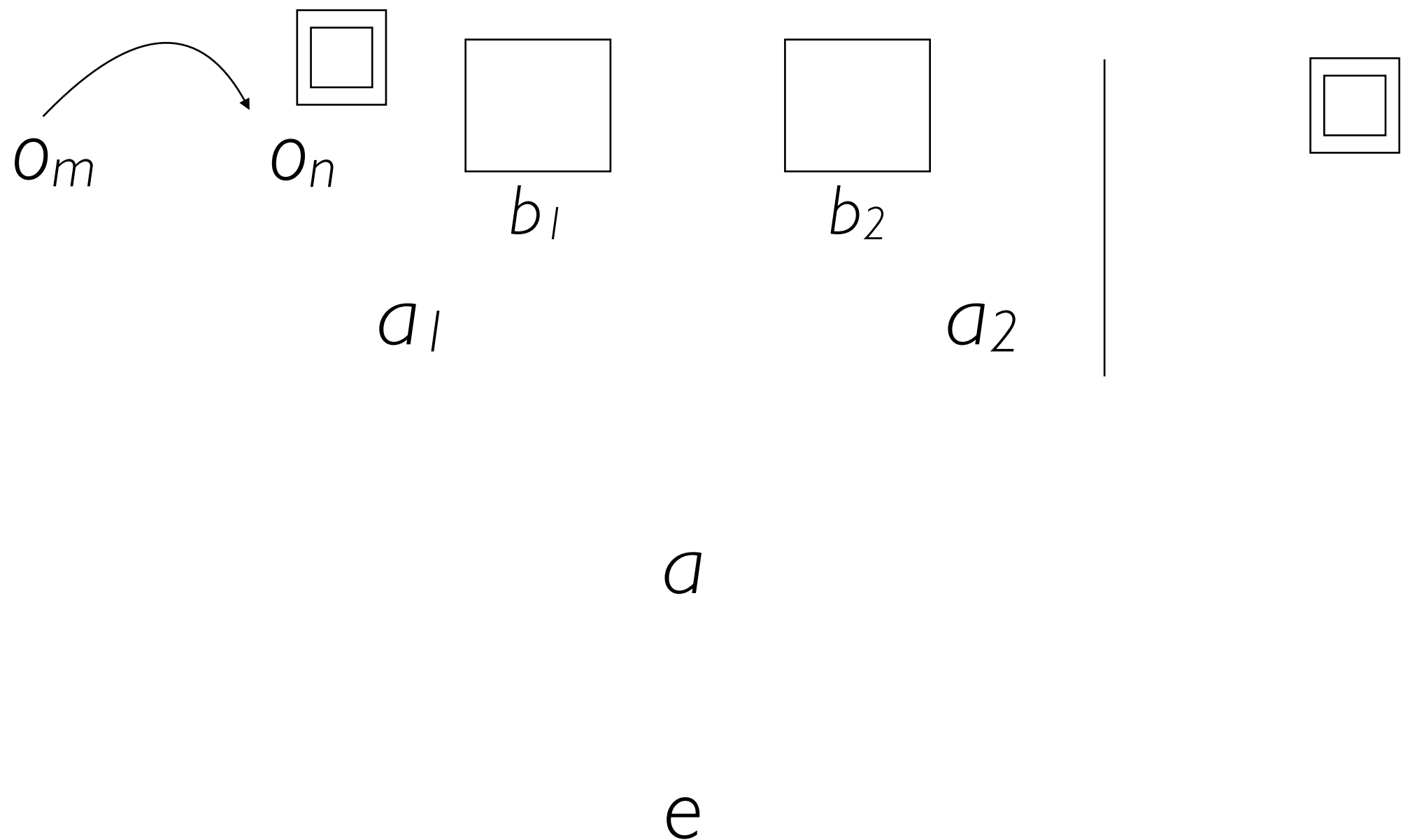
Framework for FBT^I_3

(eight timepoints)



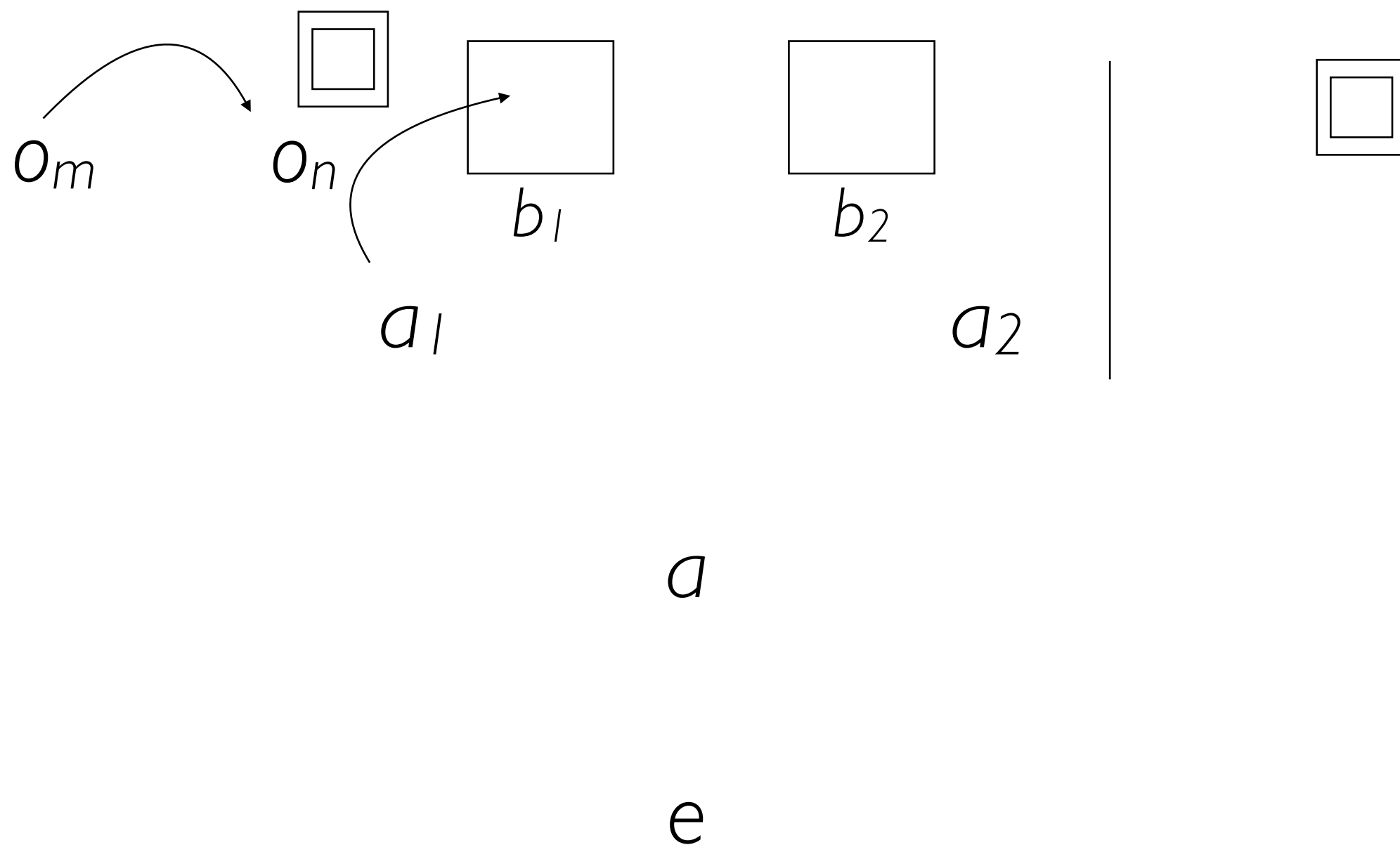
Framework for FBT^I_3

(eight timepoints)



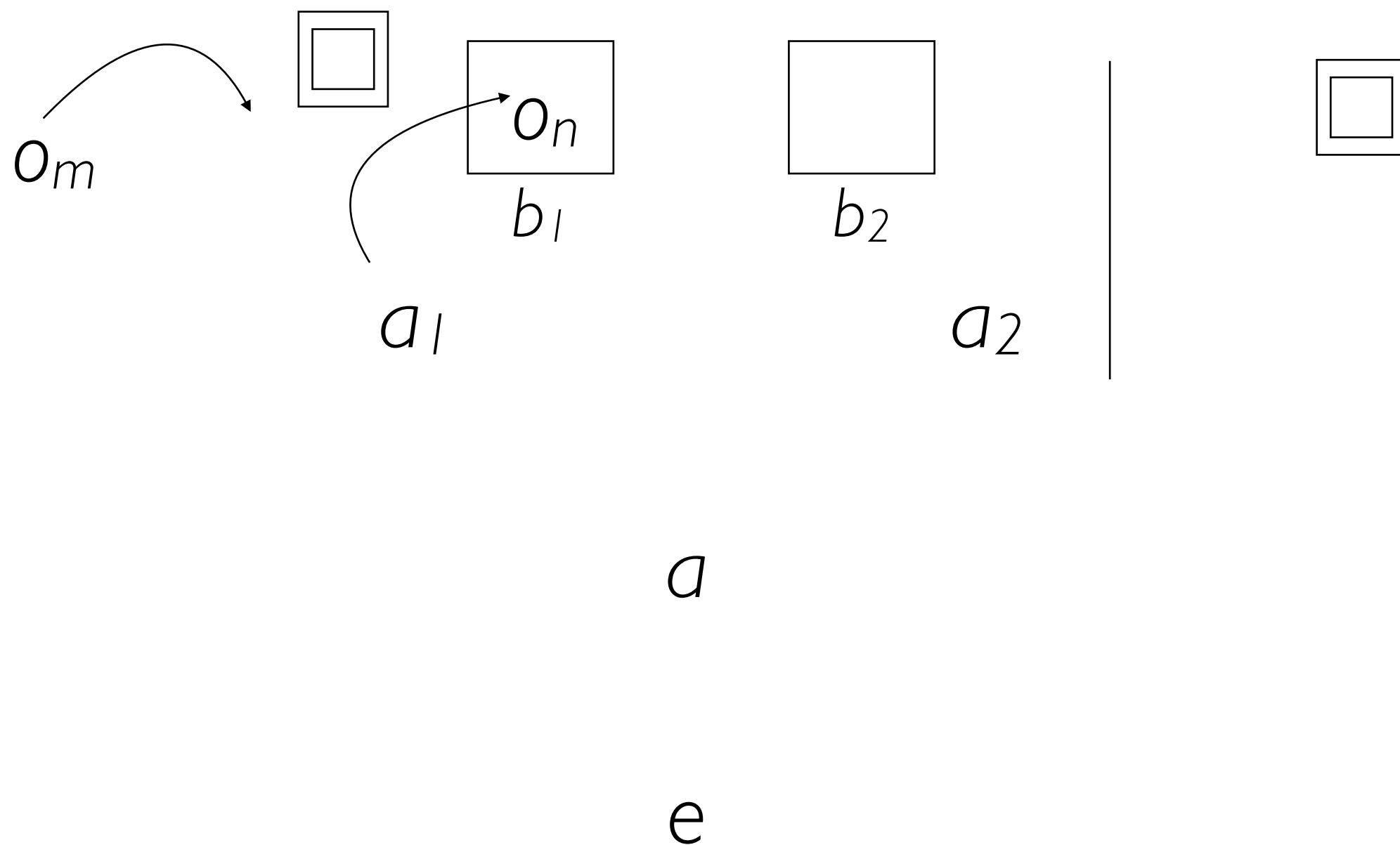
Framework for FBT^I_3

(eight timepoints)



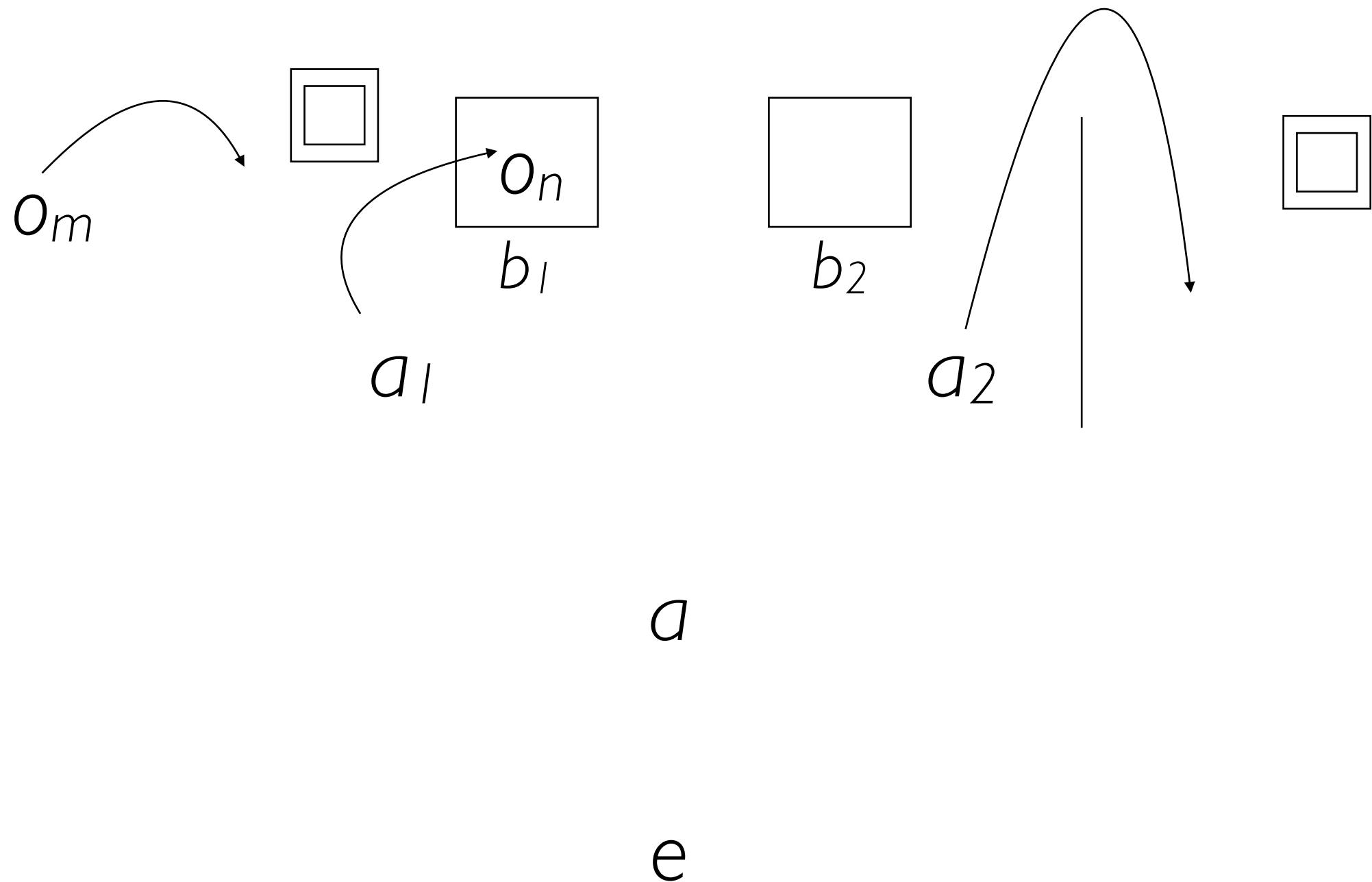
Framework for FBT^I_3

(eight timepoints)



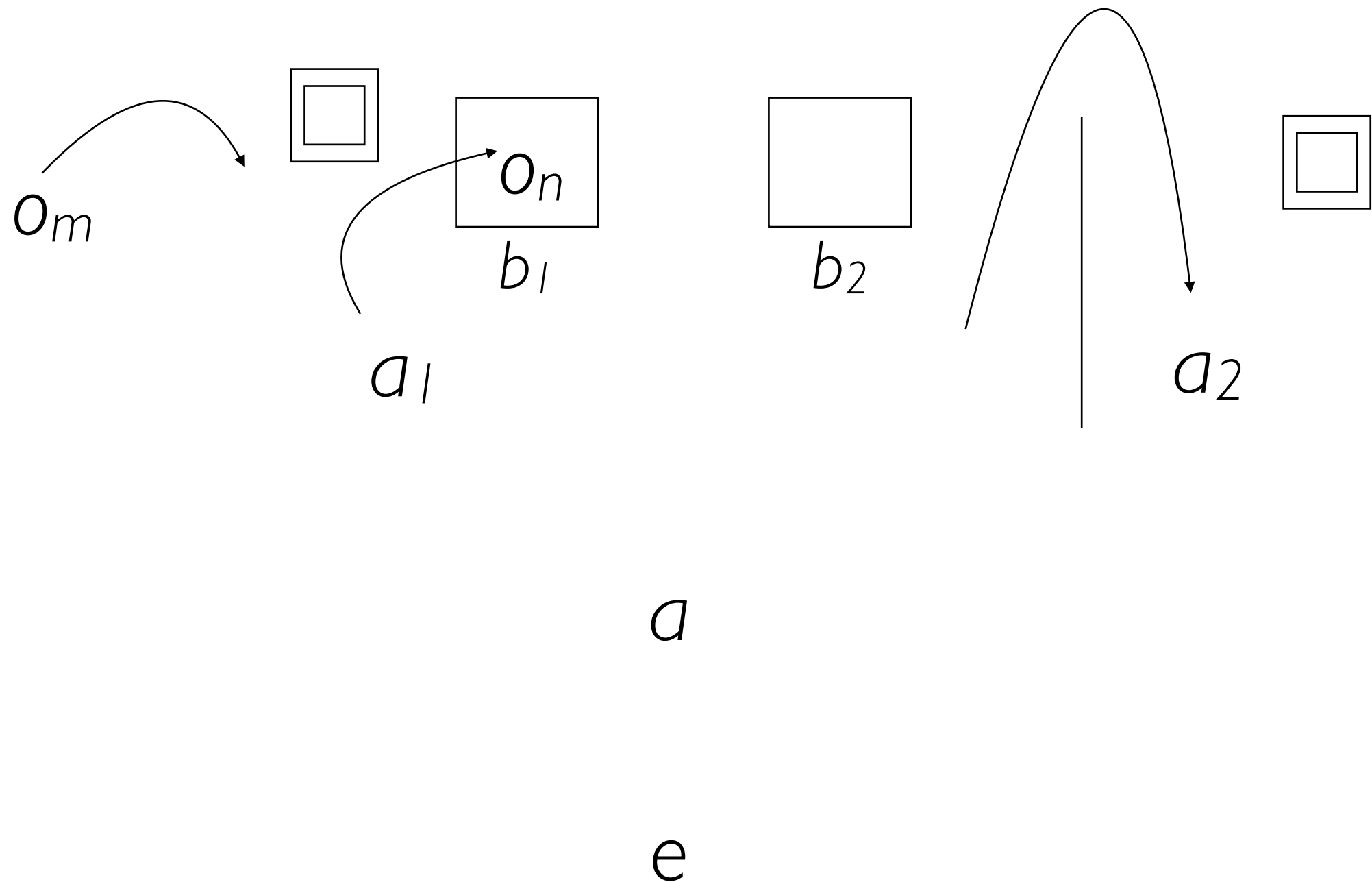
Framework for FBT^I_3

(eight timepoints)



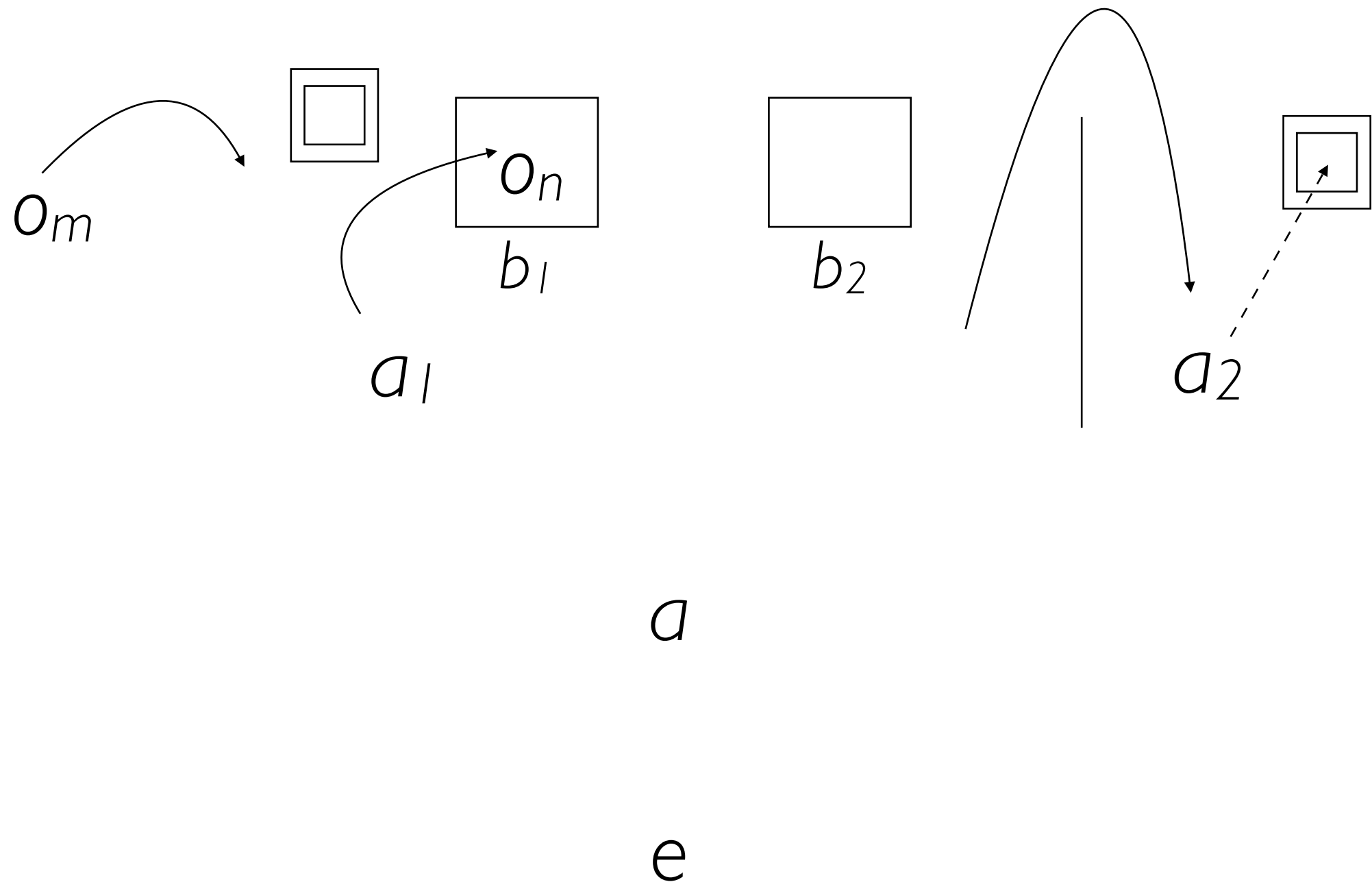
Framework for FBT^I_3

(eight timepoints)



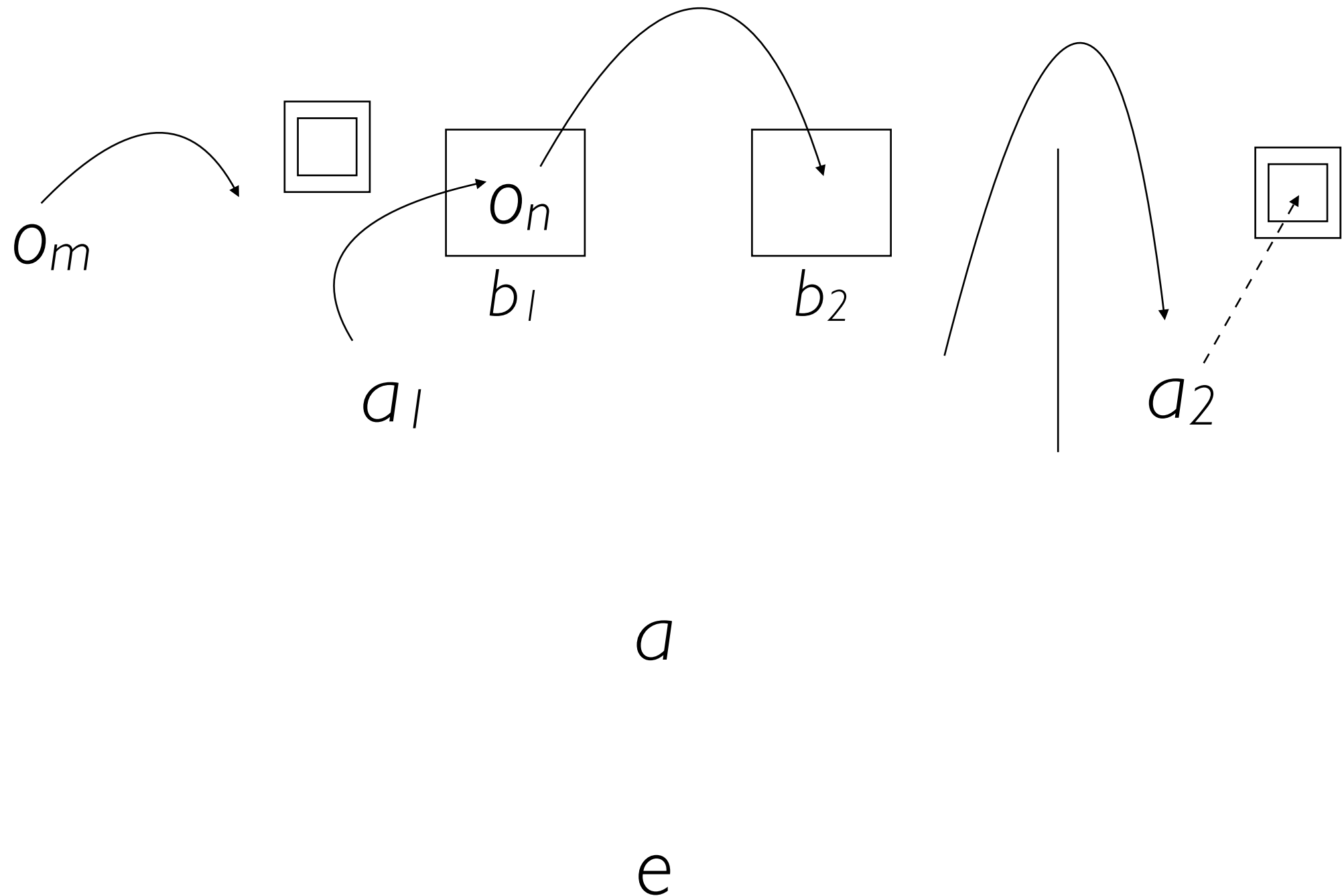
Framework for FBT^I_3

(eight timepoints)



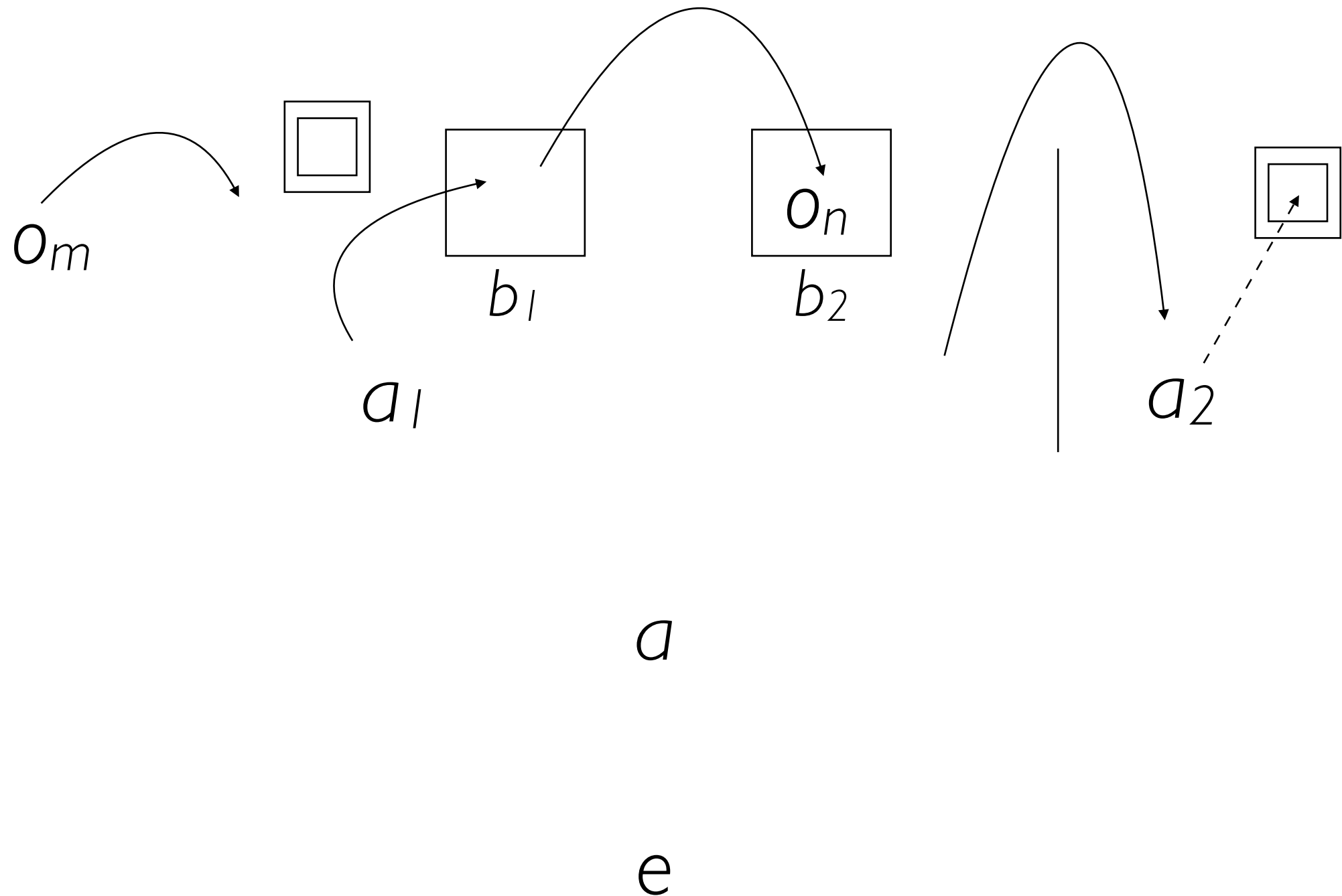
Framework for FBT^I_3

(eight timepoints)



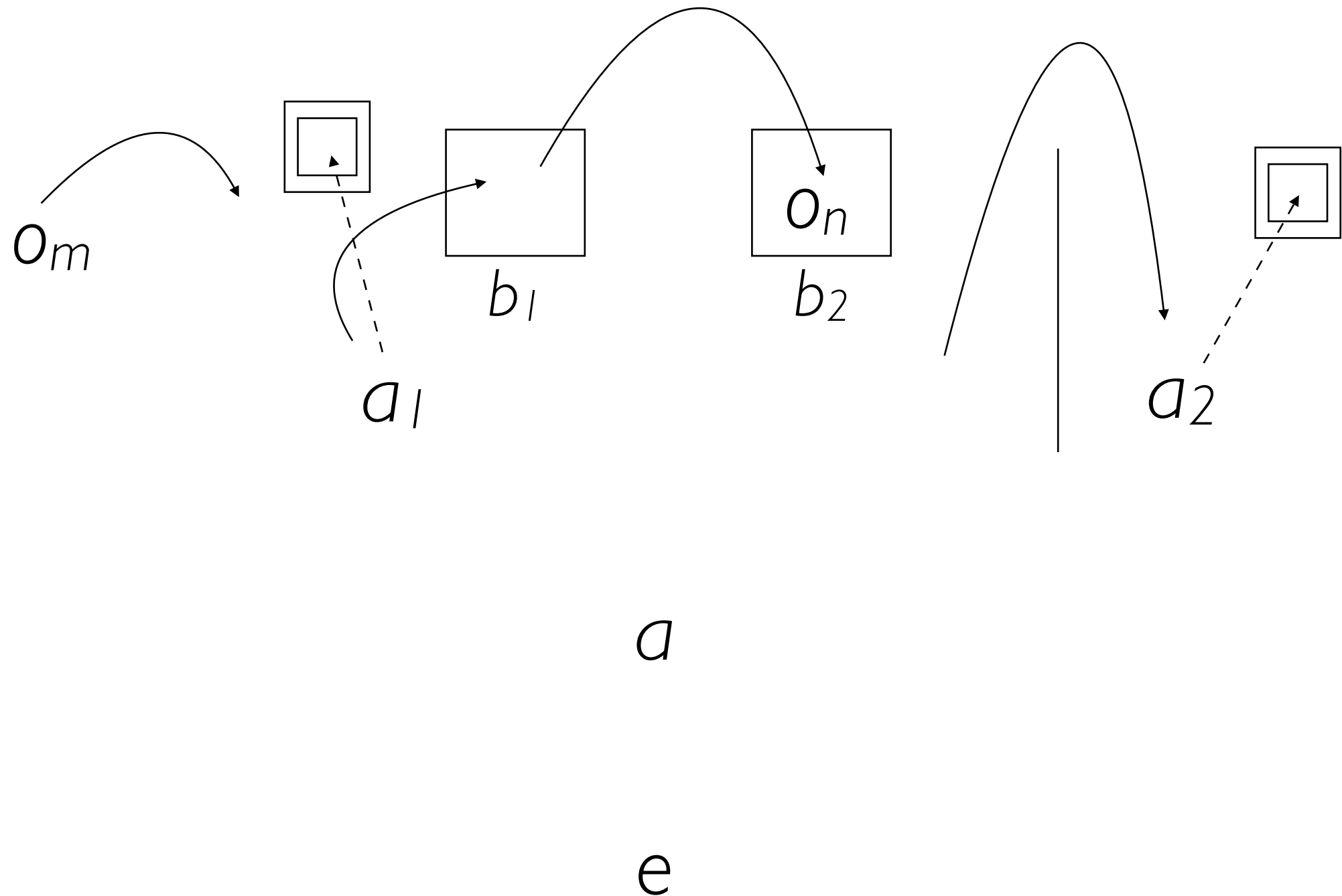
Framework for FBT^I_3

(eight timepoints)



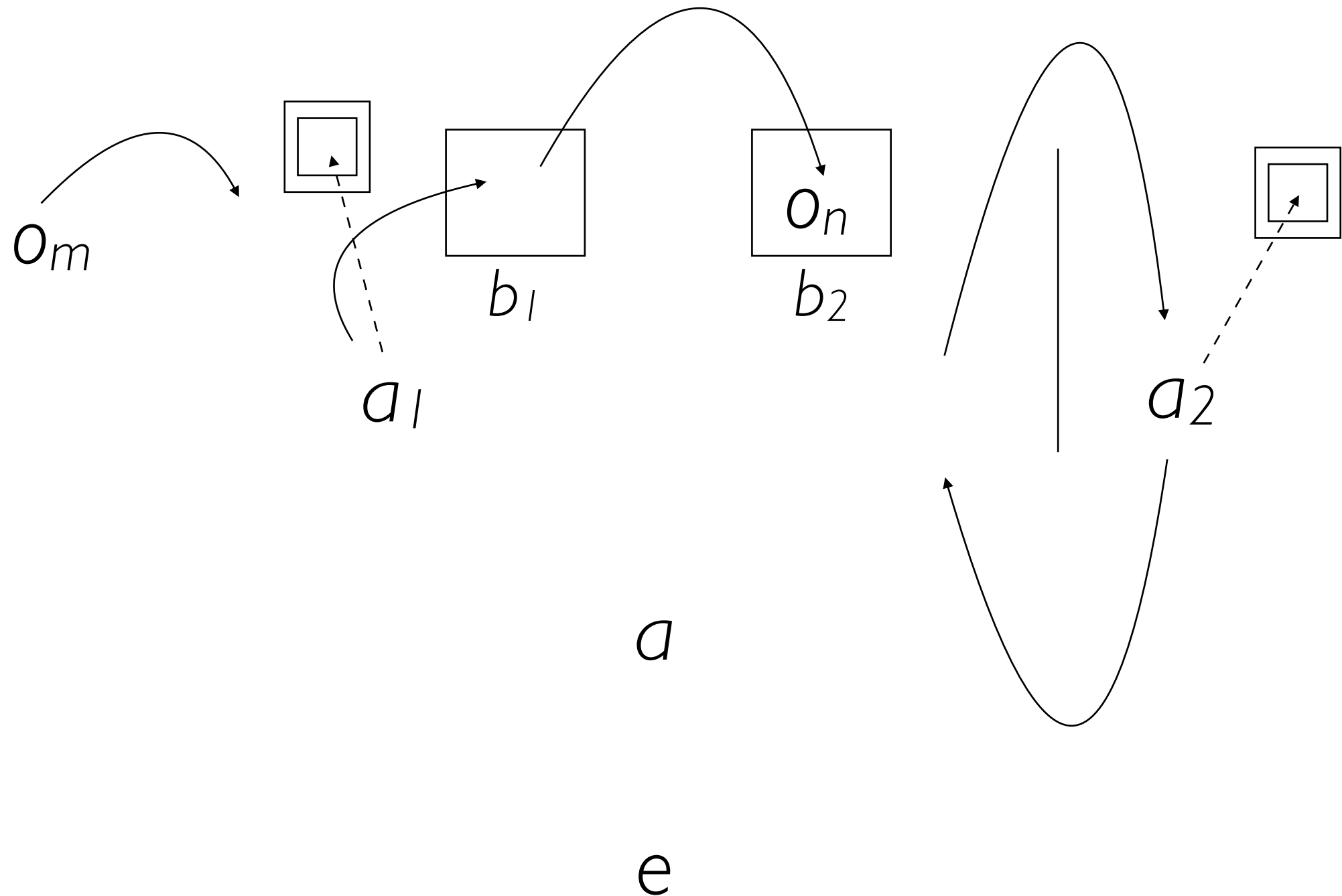
Framework for FBT^I_3

(eight timepoints)



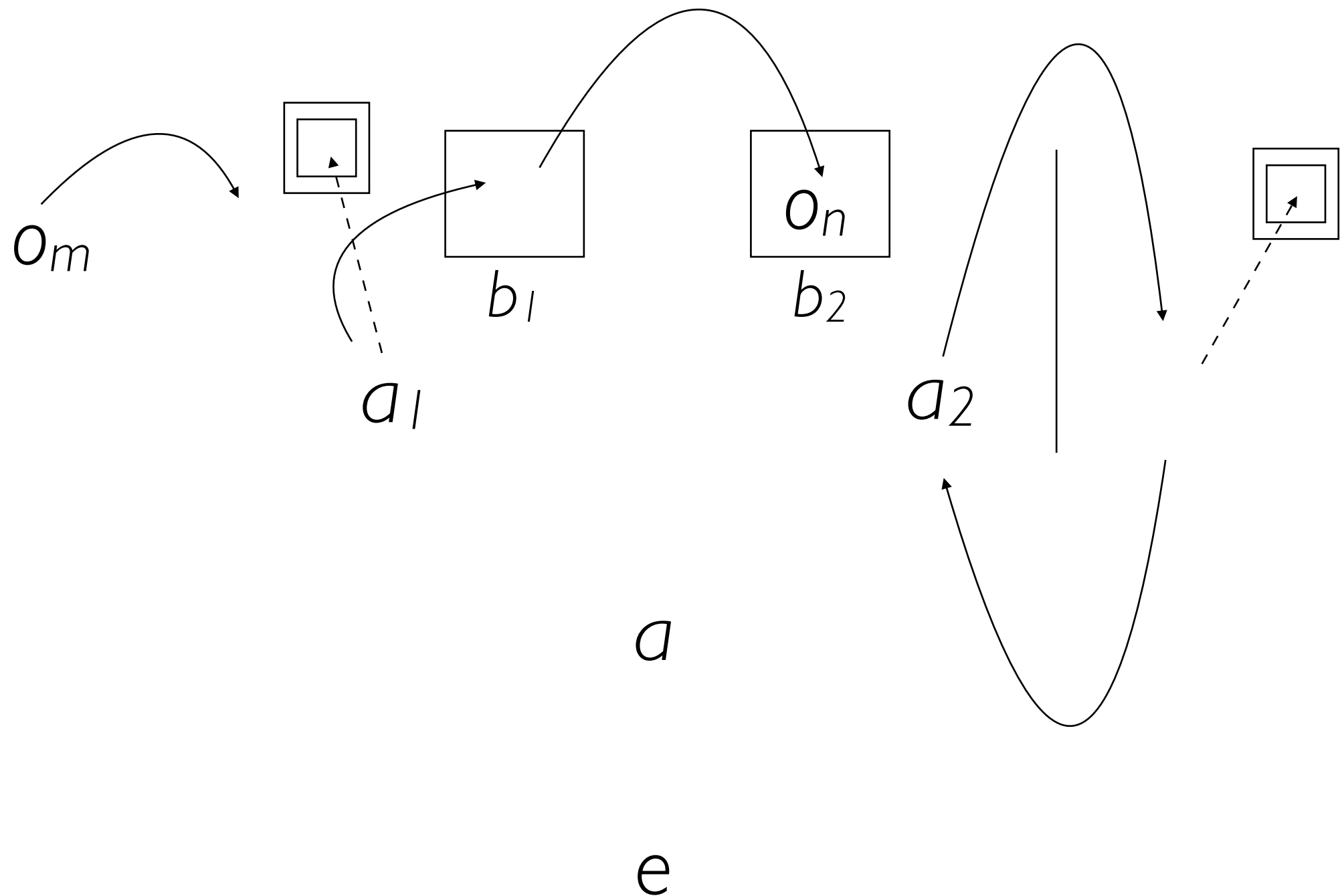
Framework for FBT^I_3

(eight timepoints)



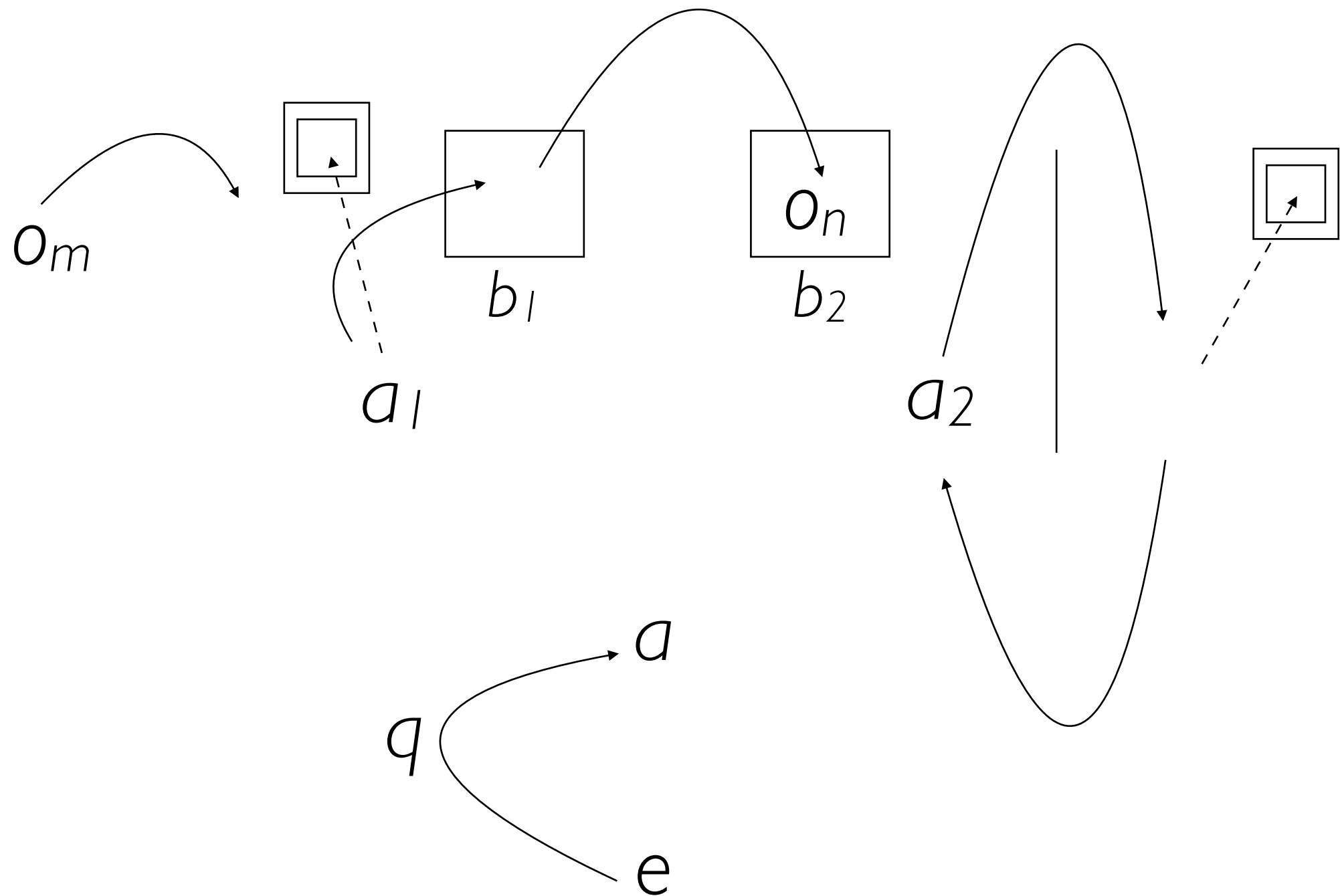
Framework for FBT^I_3

(eight timepoints)



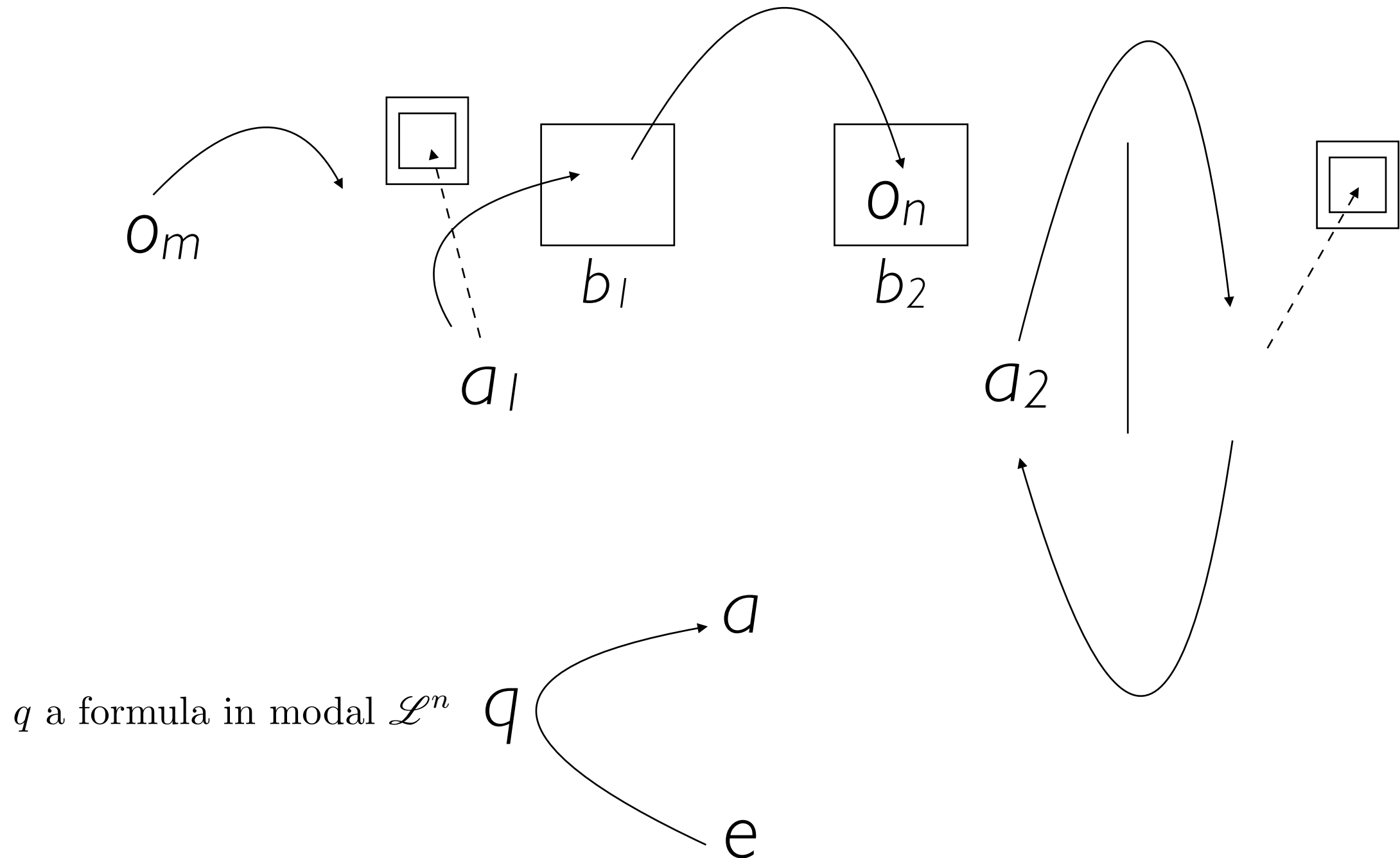
Framework for FBT^I_3

(eight timepoints)

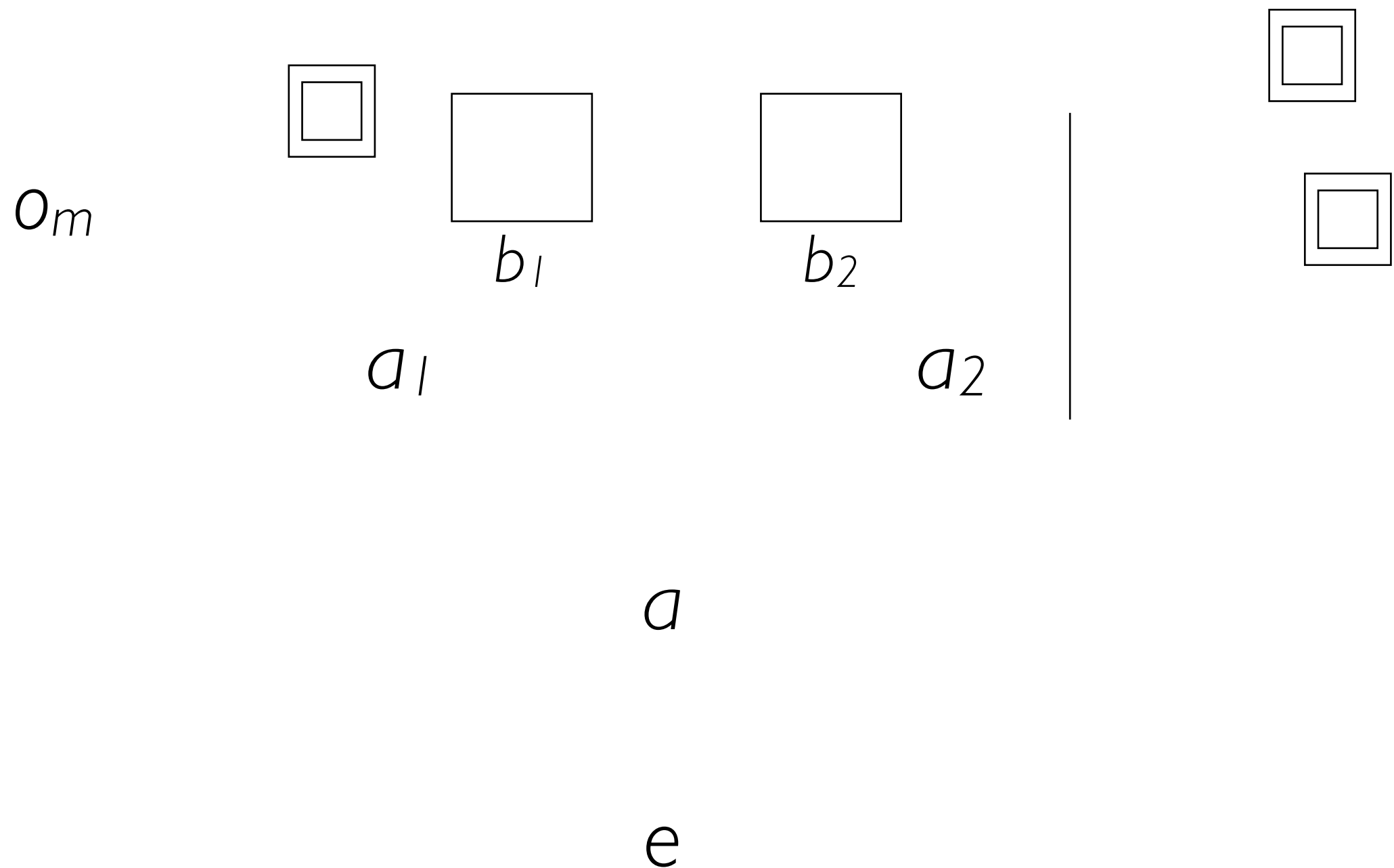


Framework for FBT^I_3

(eight timepoints)

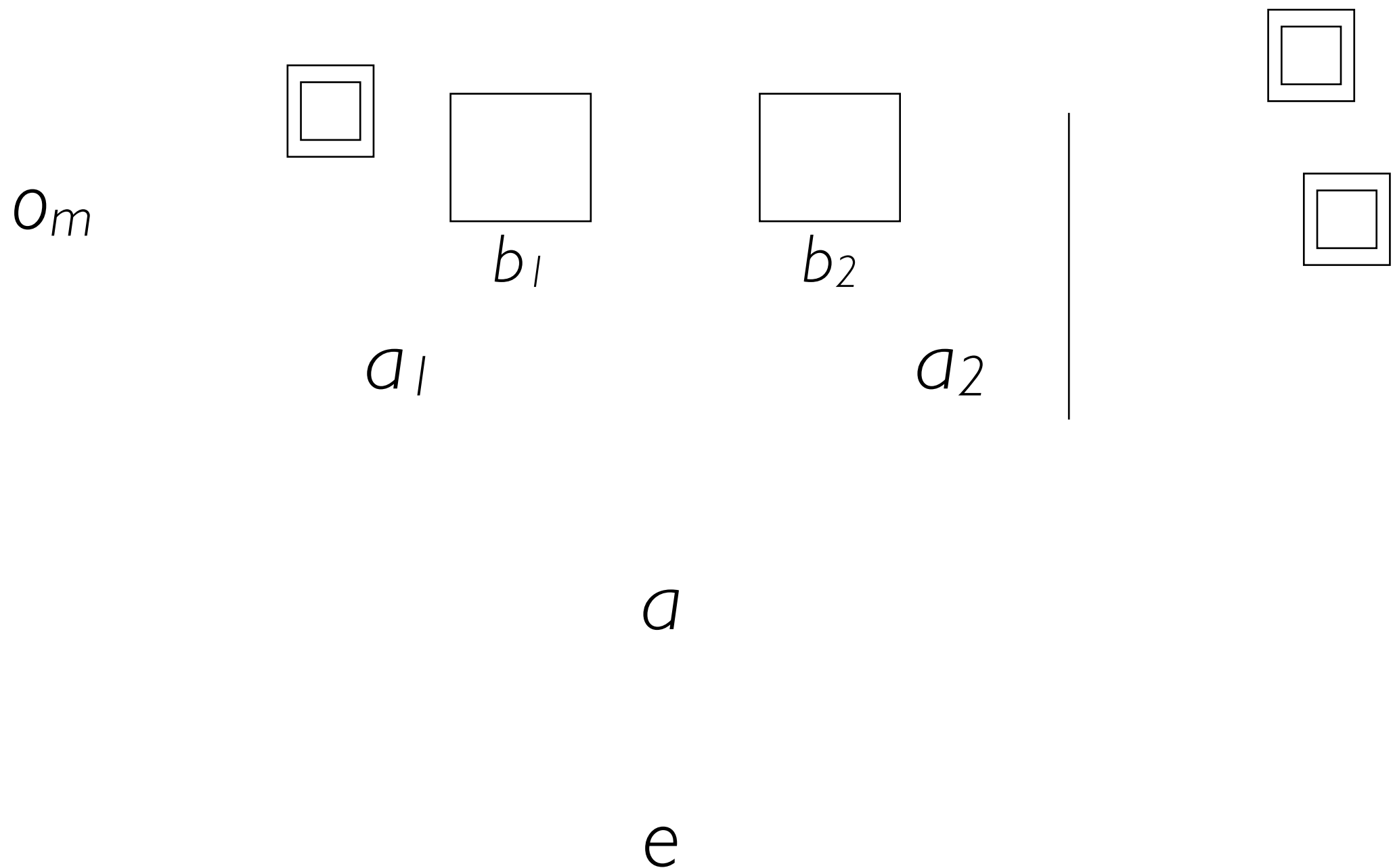


Framework for FBT^I_4



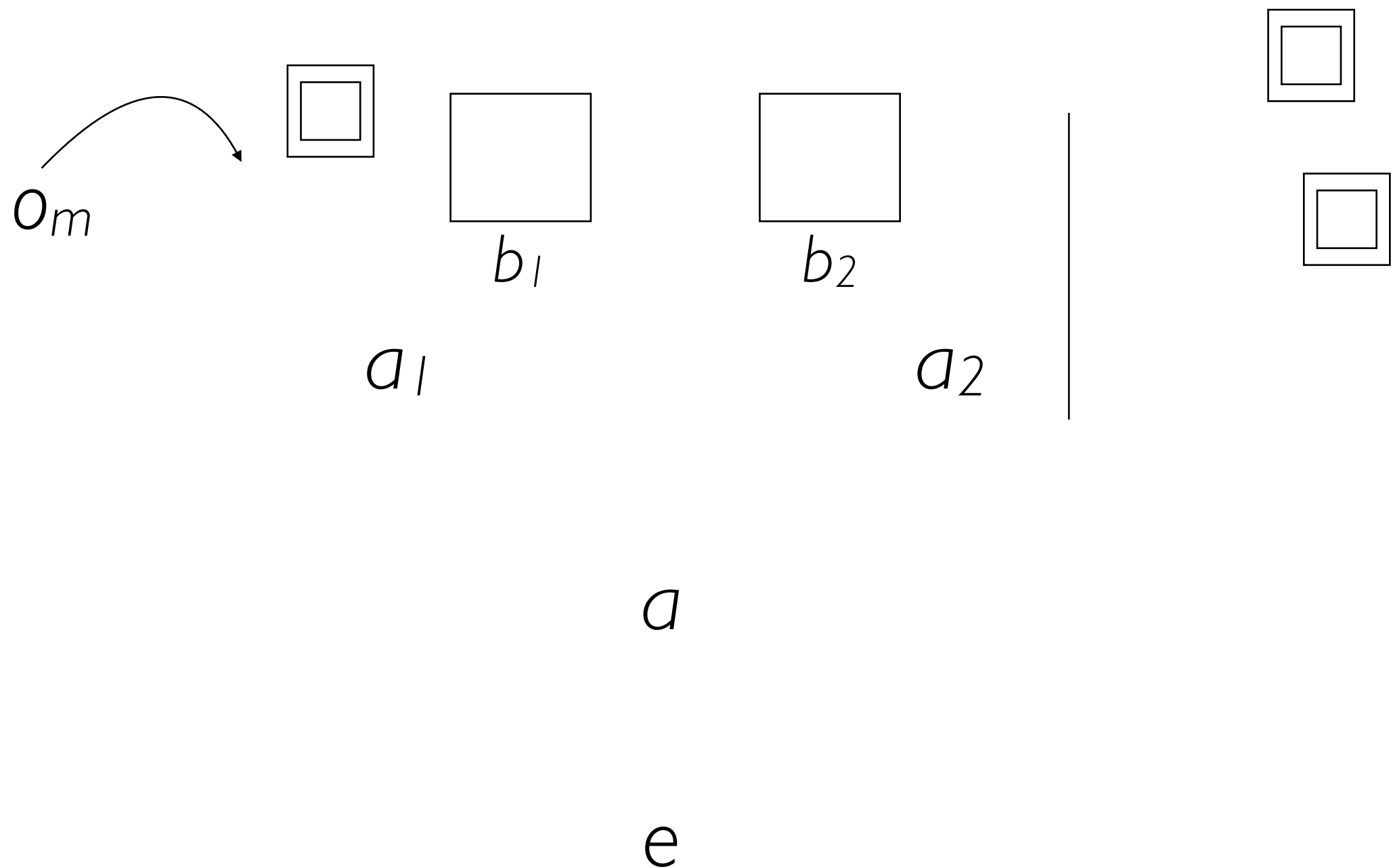
Framework for FBT^I_4

(nine timepoints)



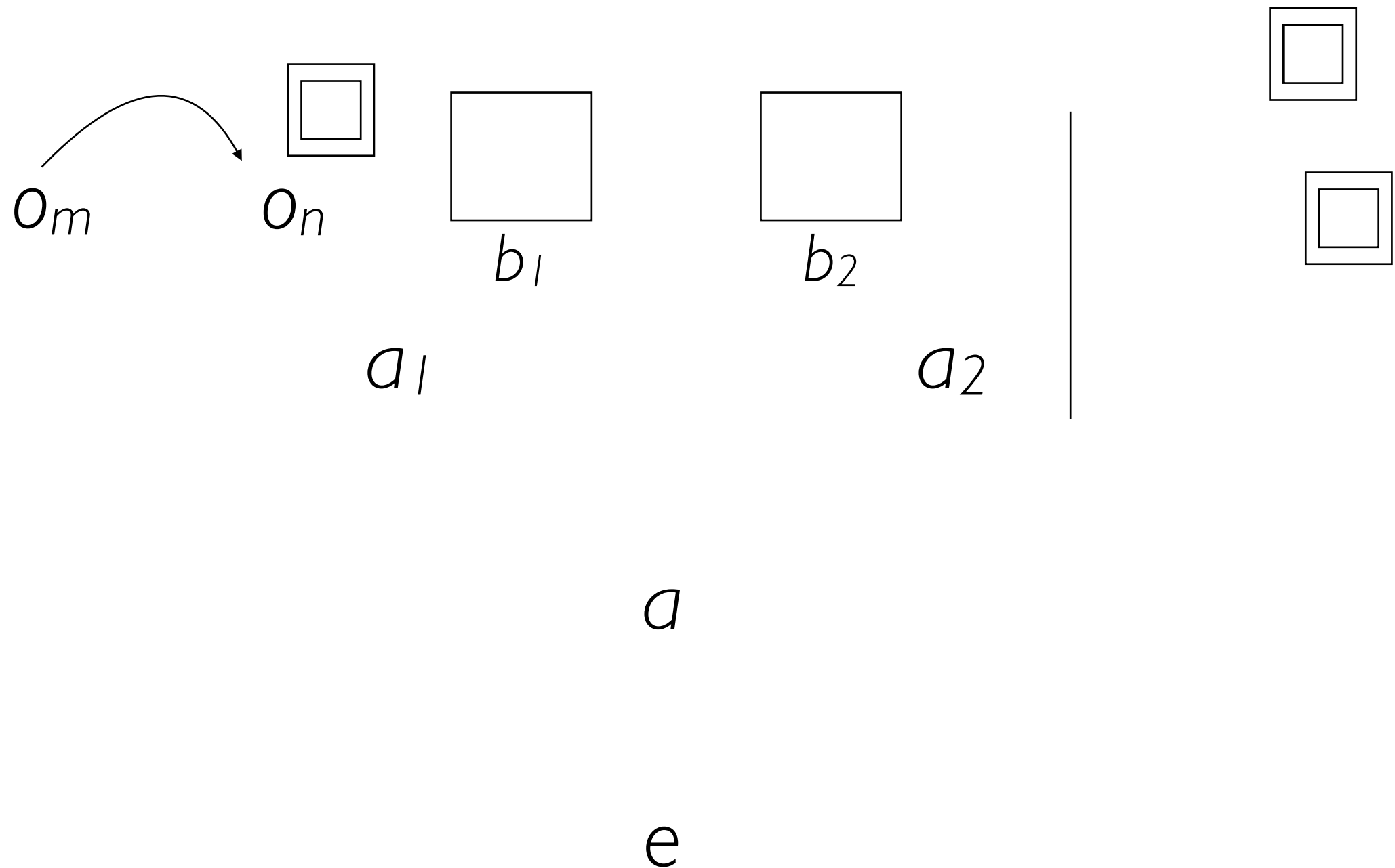
Framework for FBT^I_4

(nine timepoints)



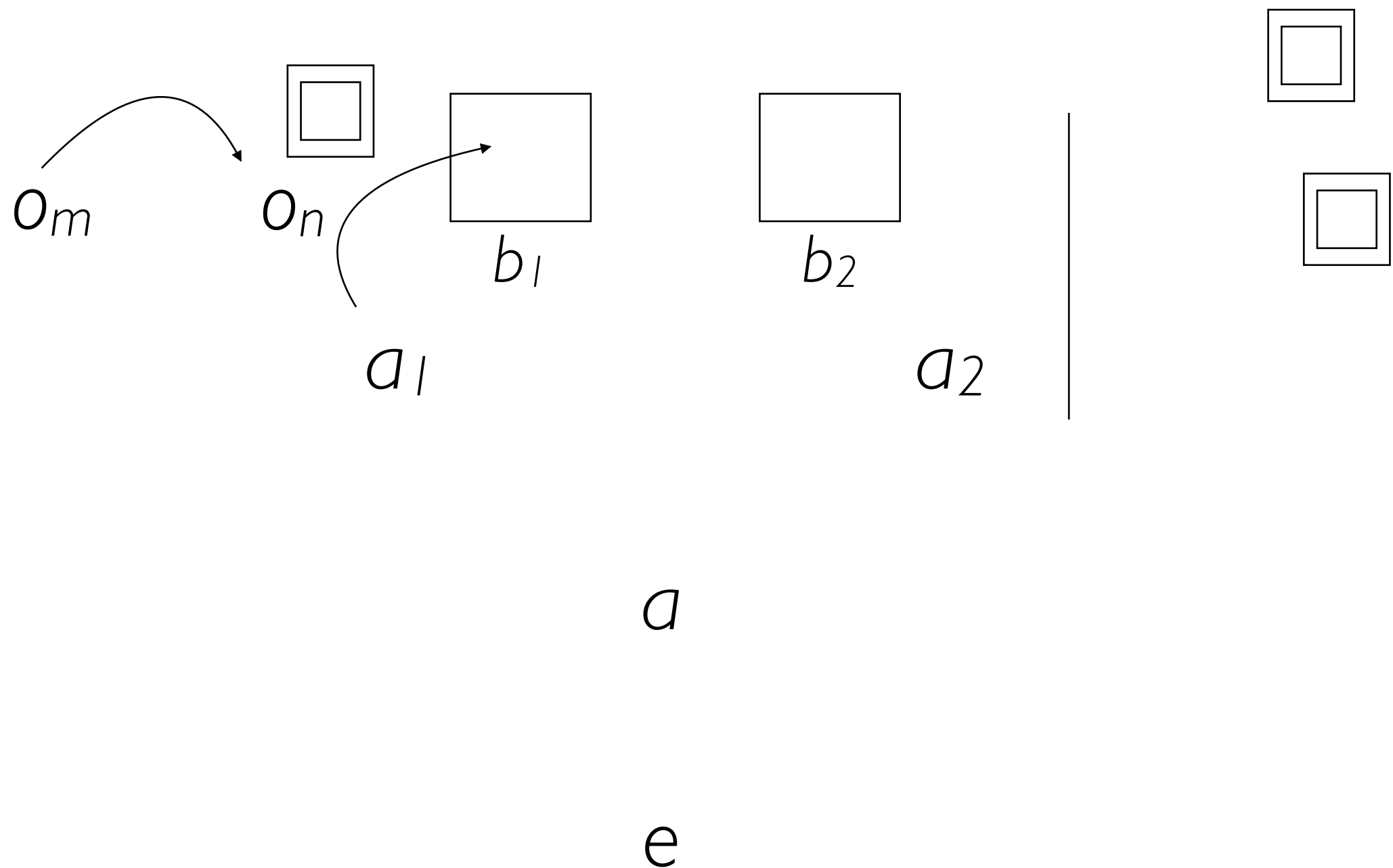
Framework for FBT^I_4

(nine timepoints)



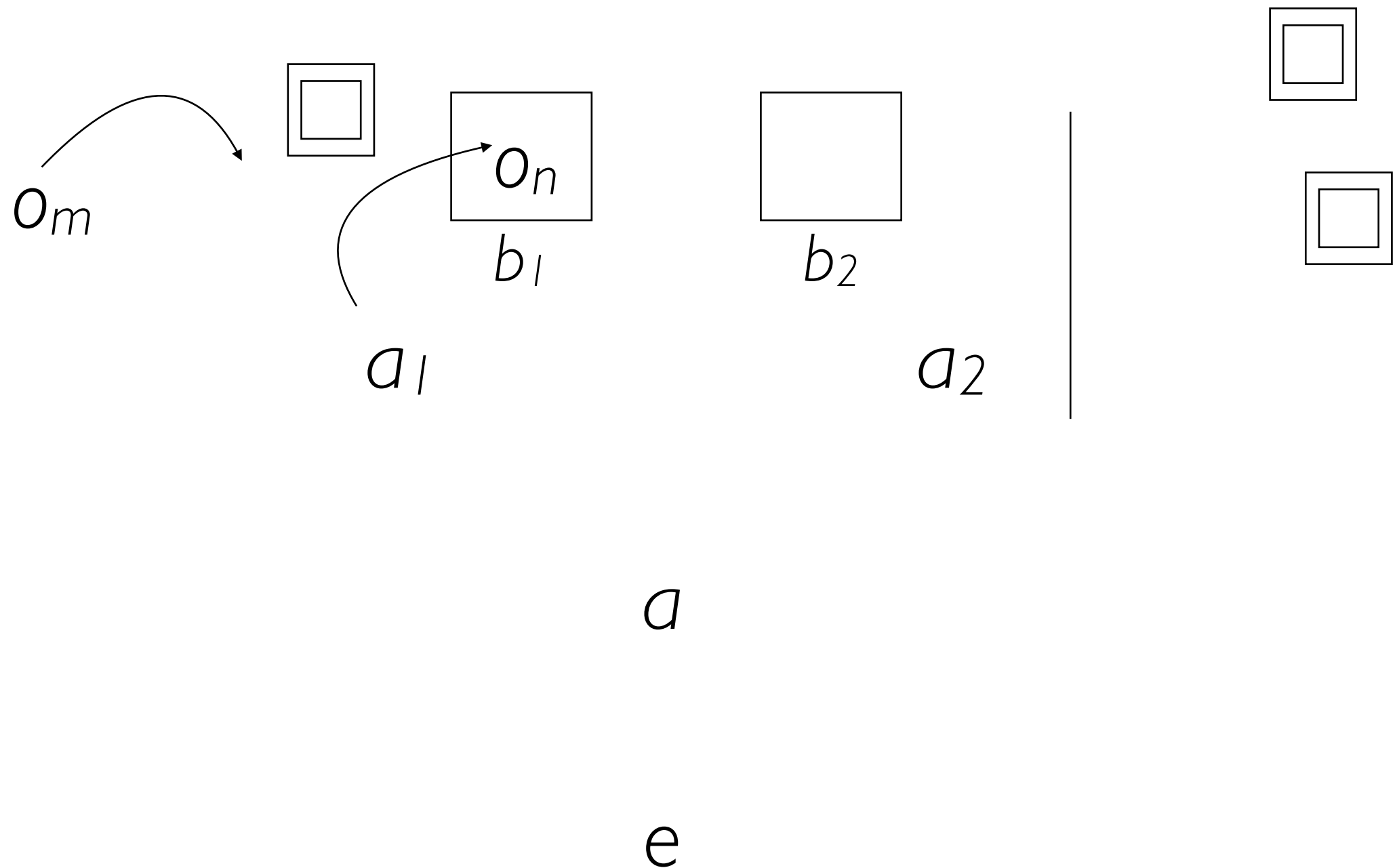
Framework for FBT^I_4

(nine timepoints)



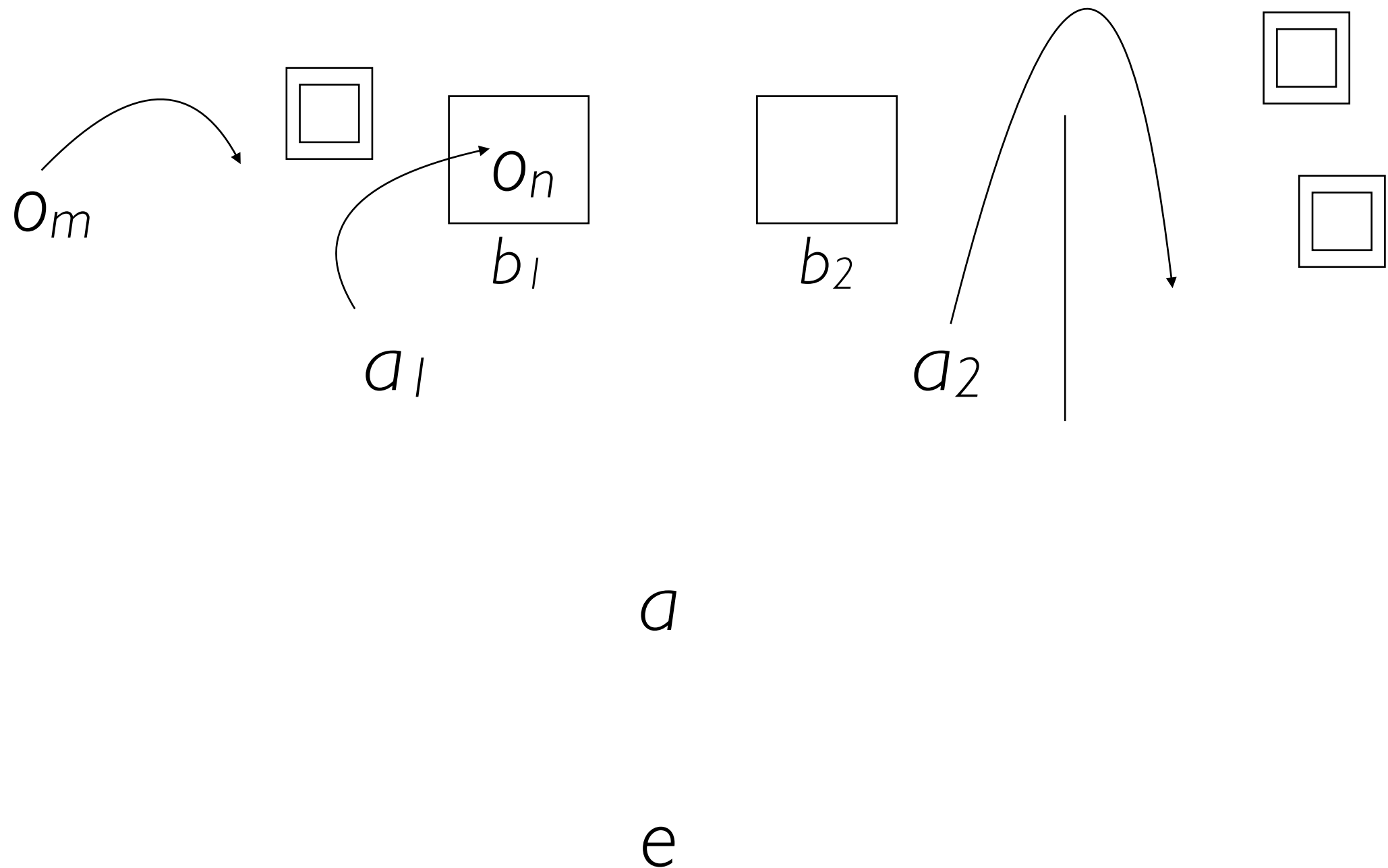
Framework for FBT^I_4

(nine timepoints)



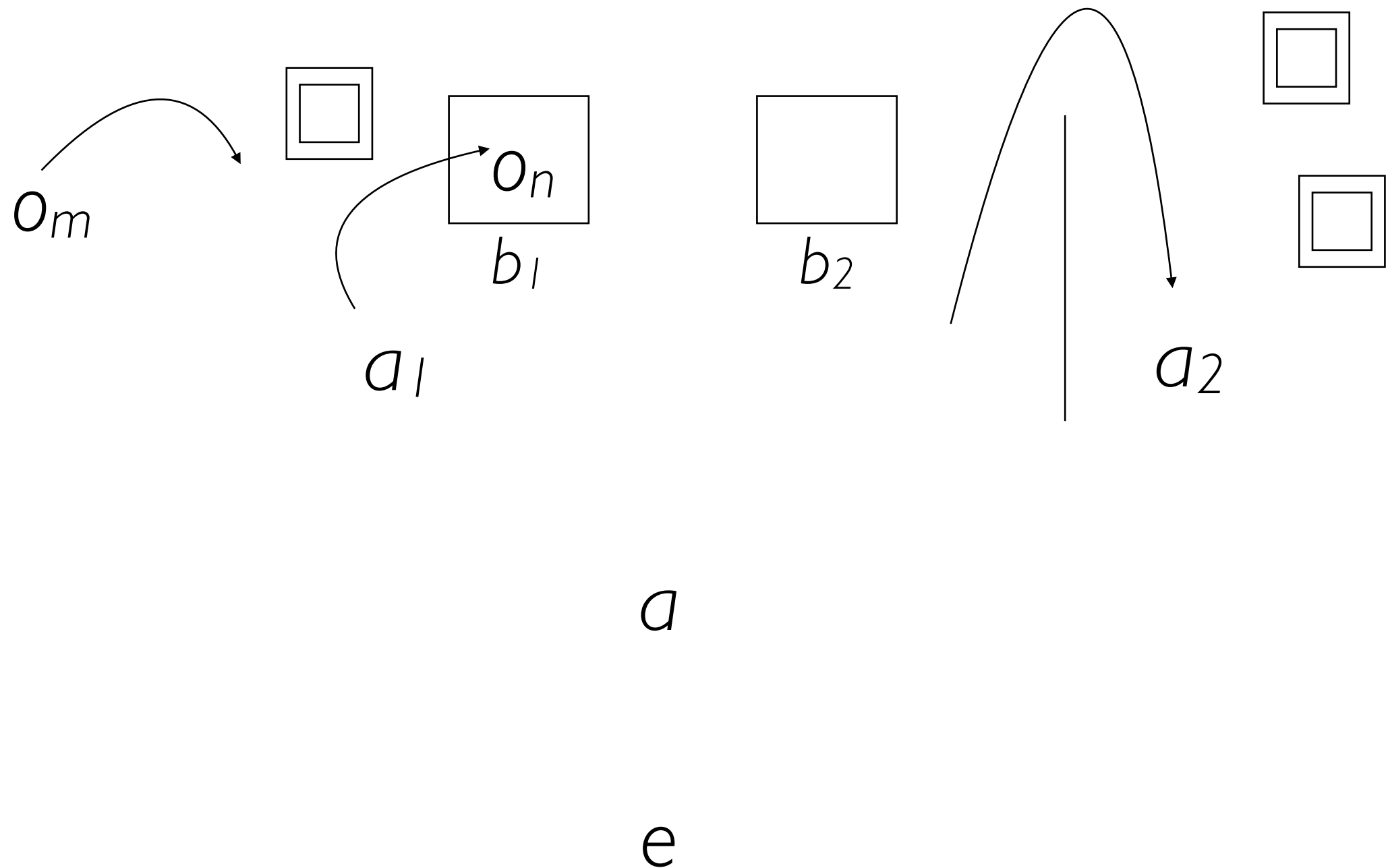
Framework for FBT^I_4

(nine timepoints)



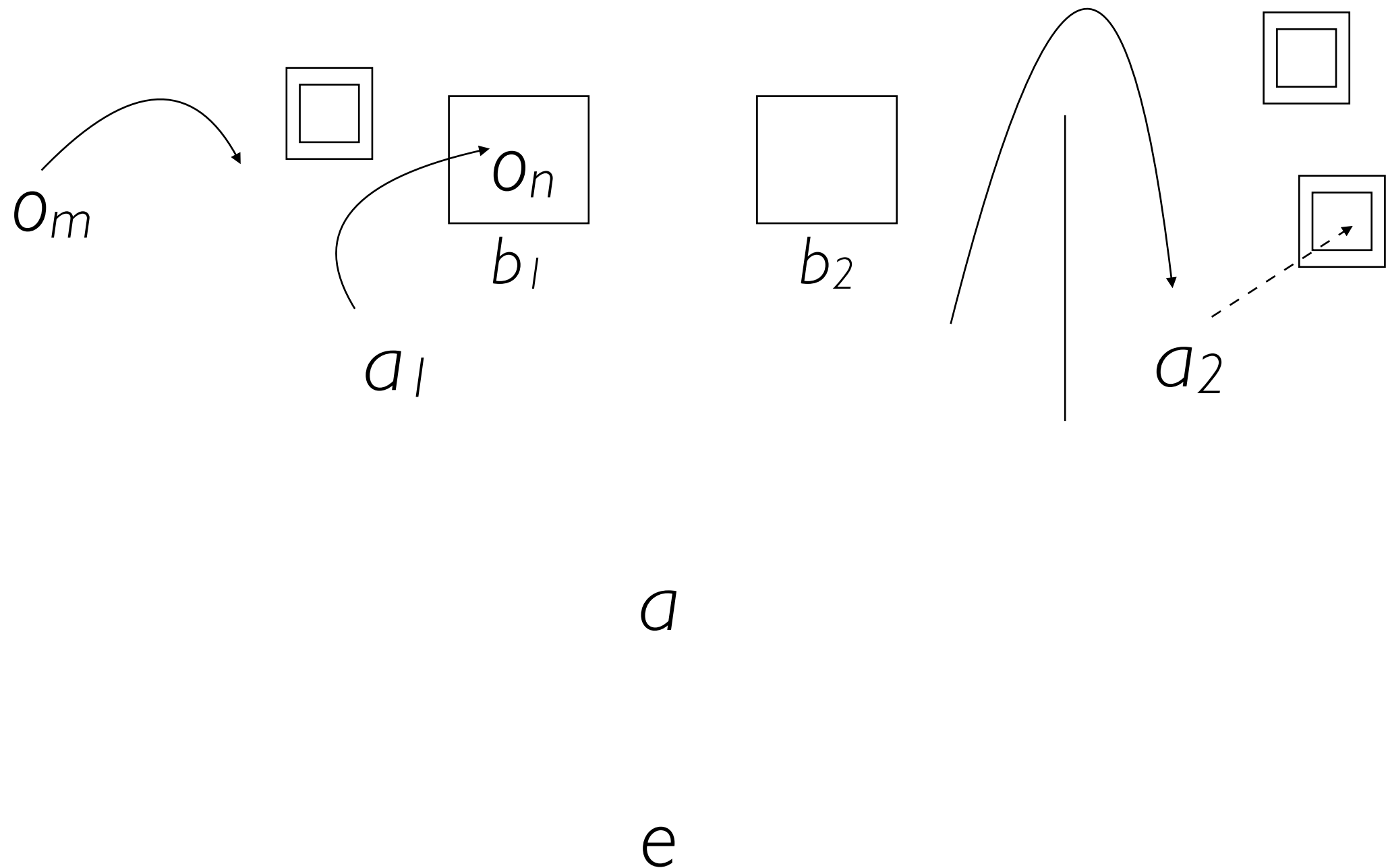
Framework for FBT^I_4

(nine timepoints)



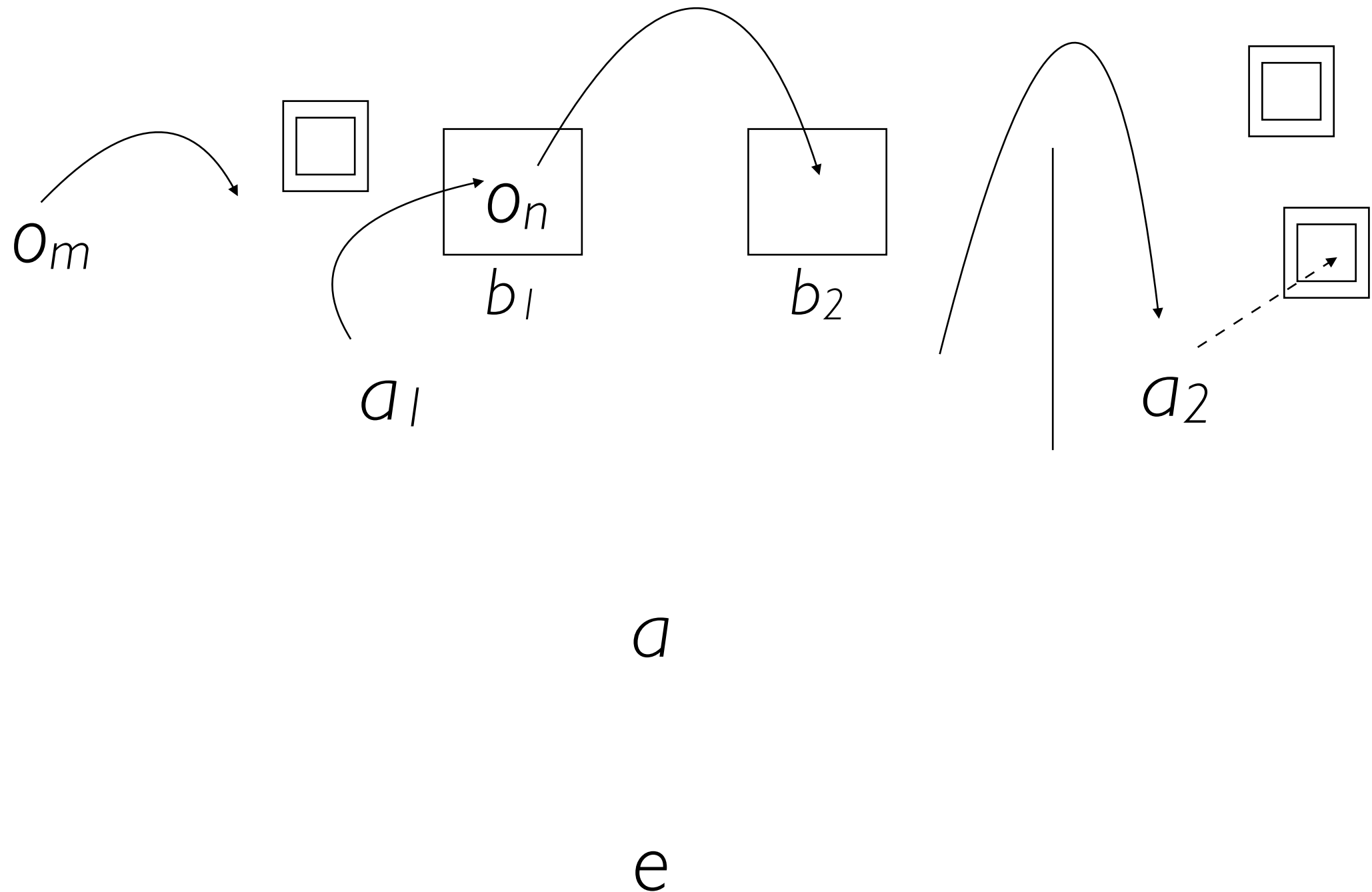
Framework for FBT^I_4

(nine timepoints)



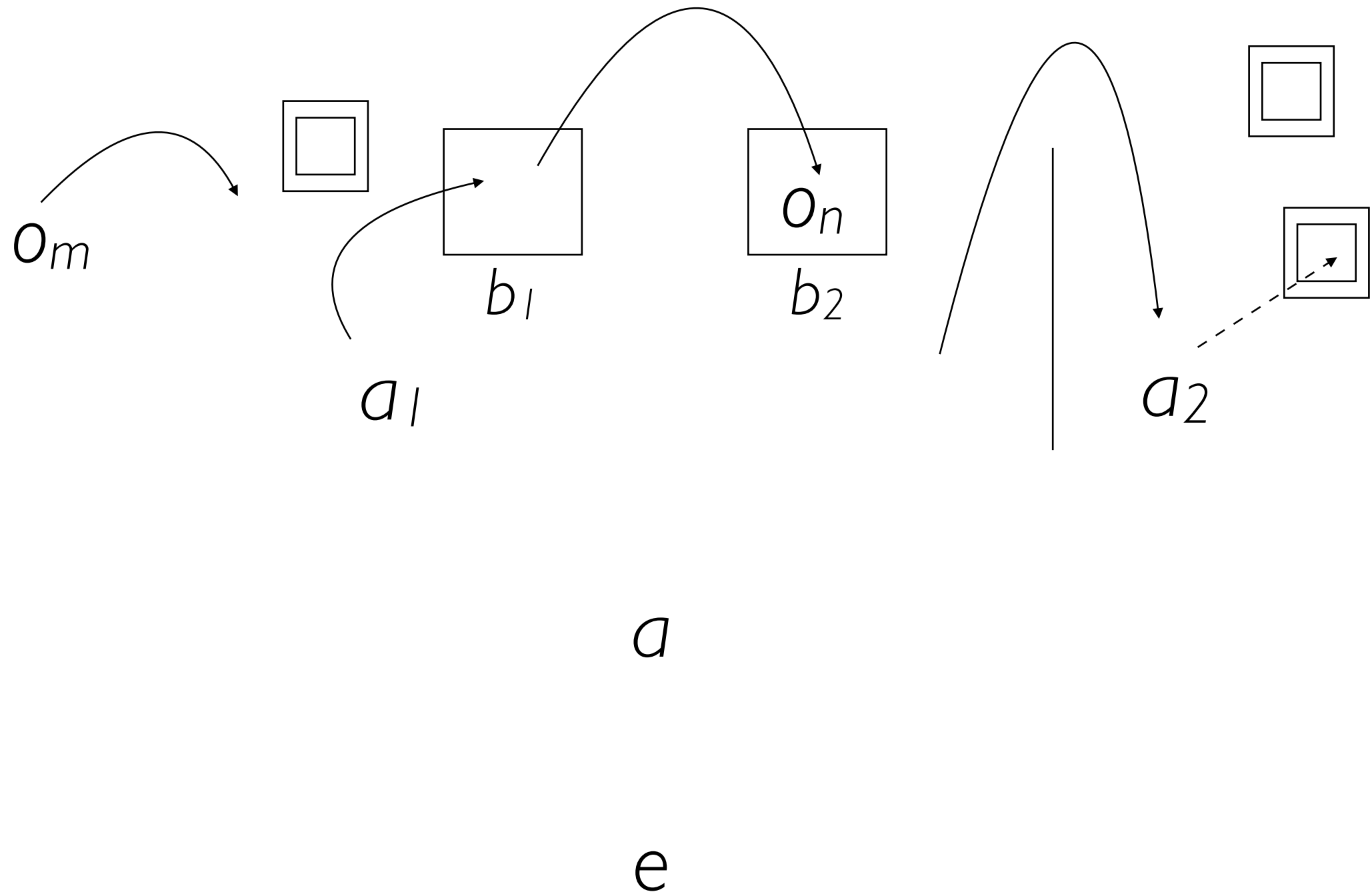
Framework for FBT^I_4

(nine timepoints)



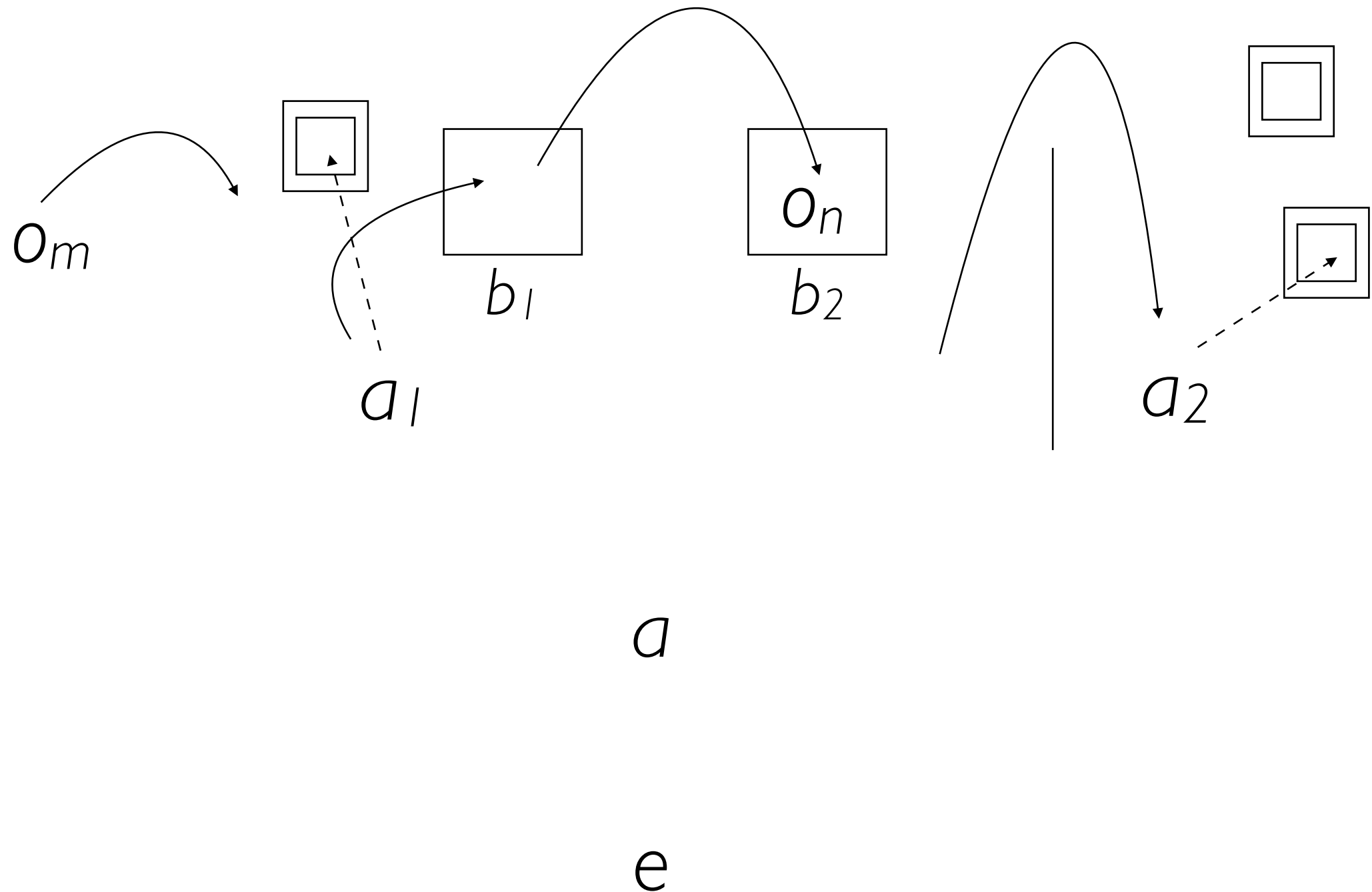
Framework for FBT^I_4

(nine timepoints)



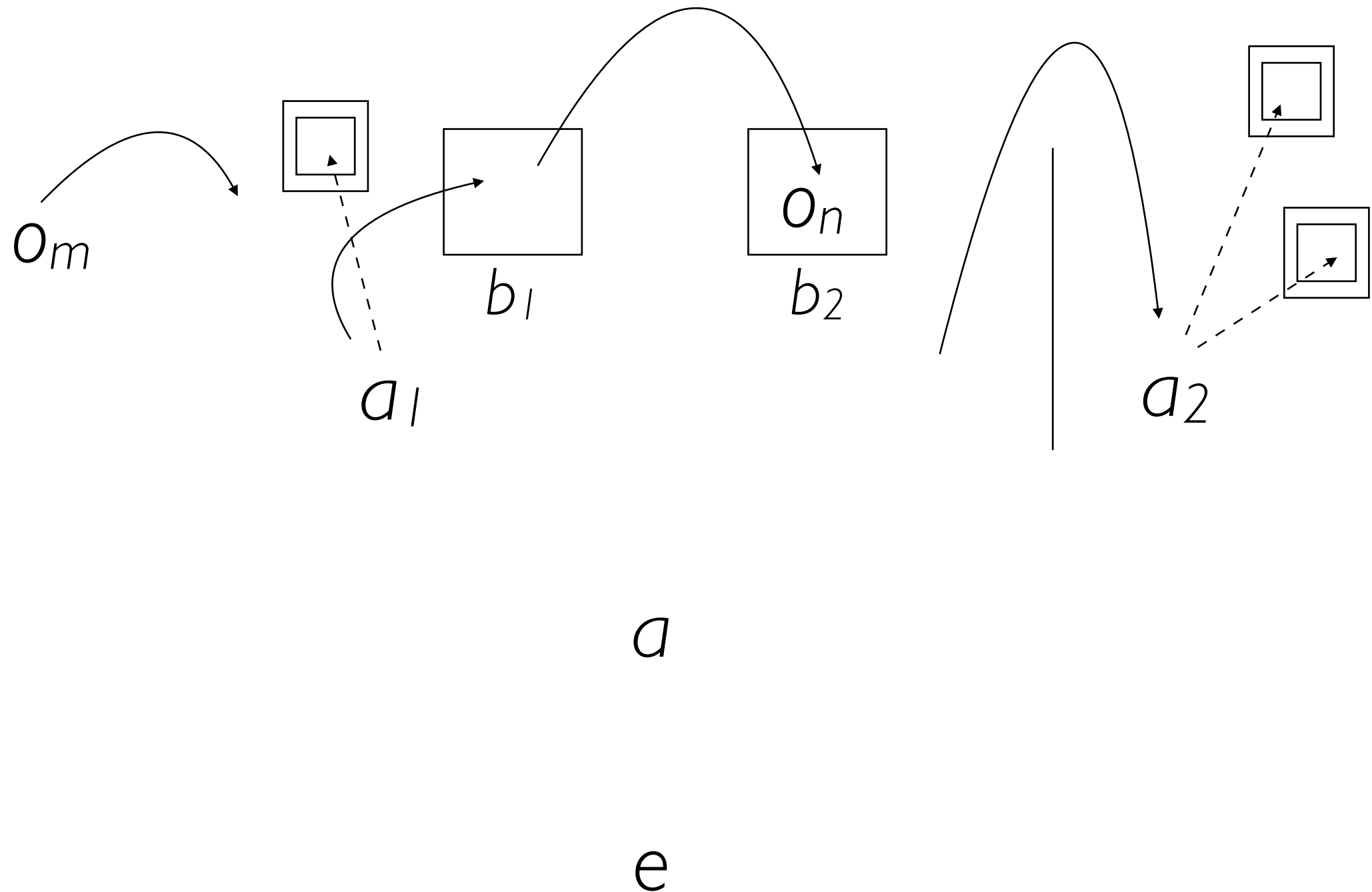
Framework for FBT^I_4

(nine timepoints)



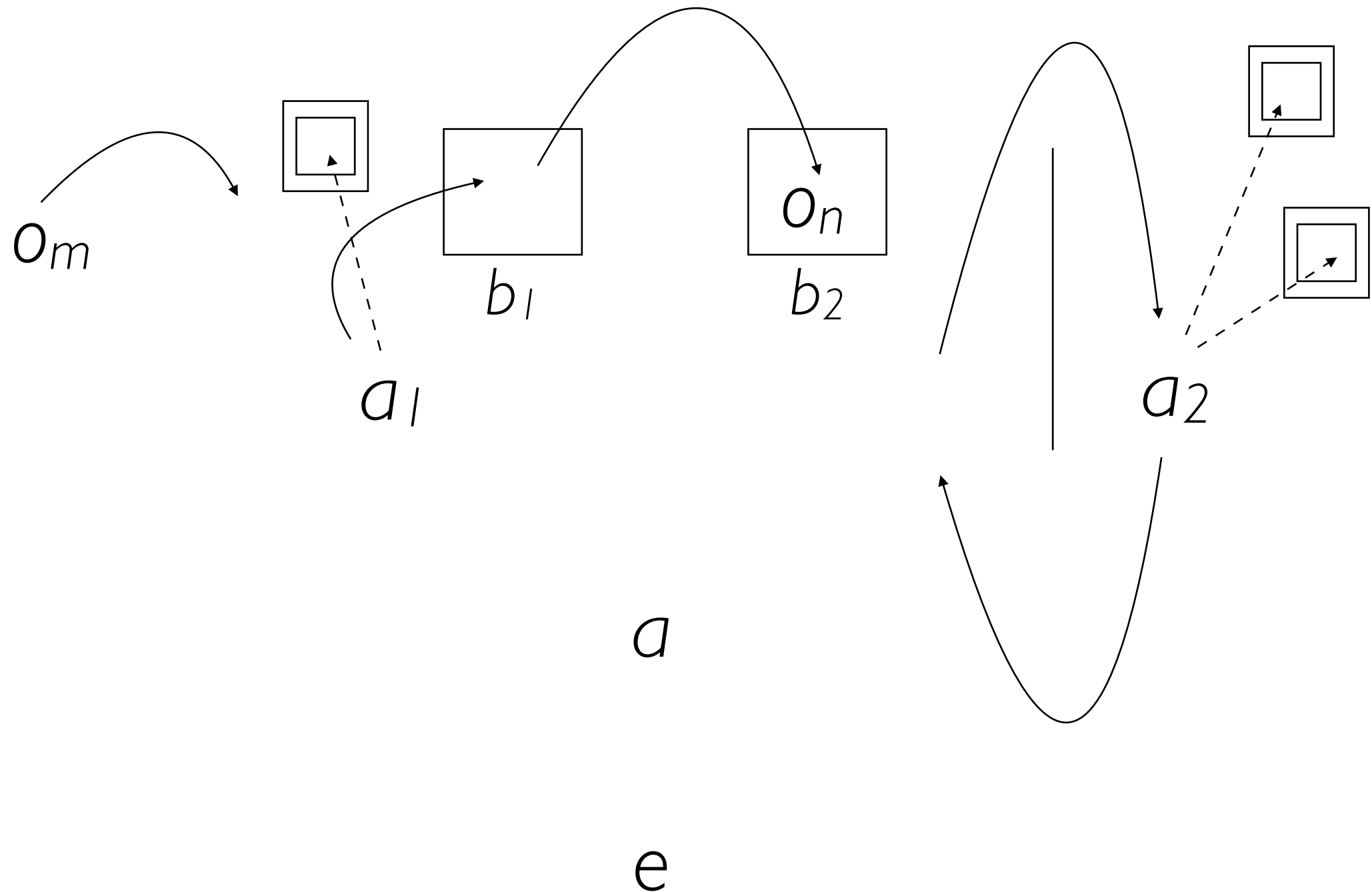
Framework for FBT^I_4

(nine timepoints)



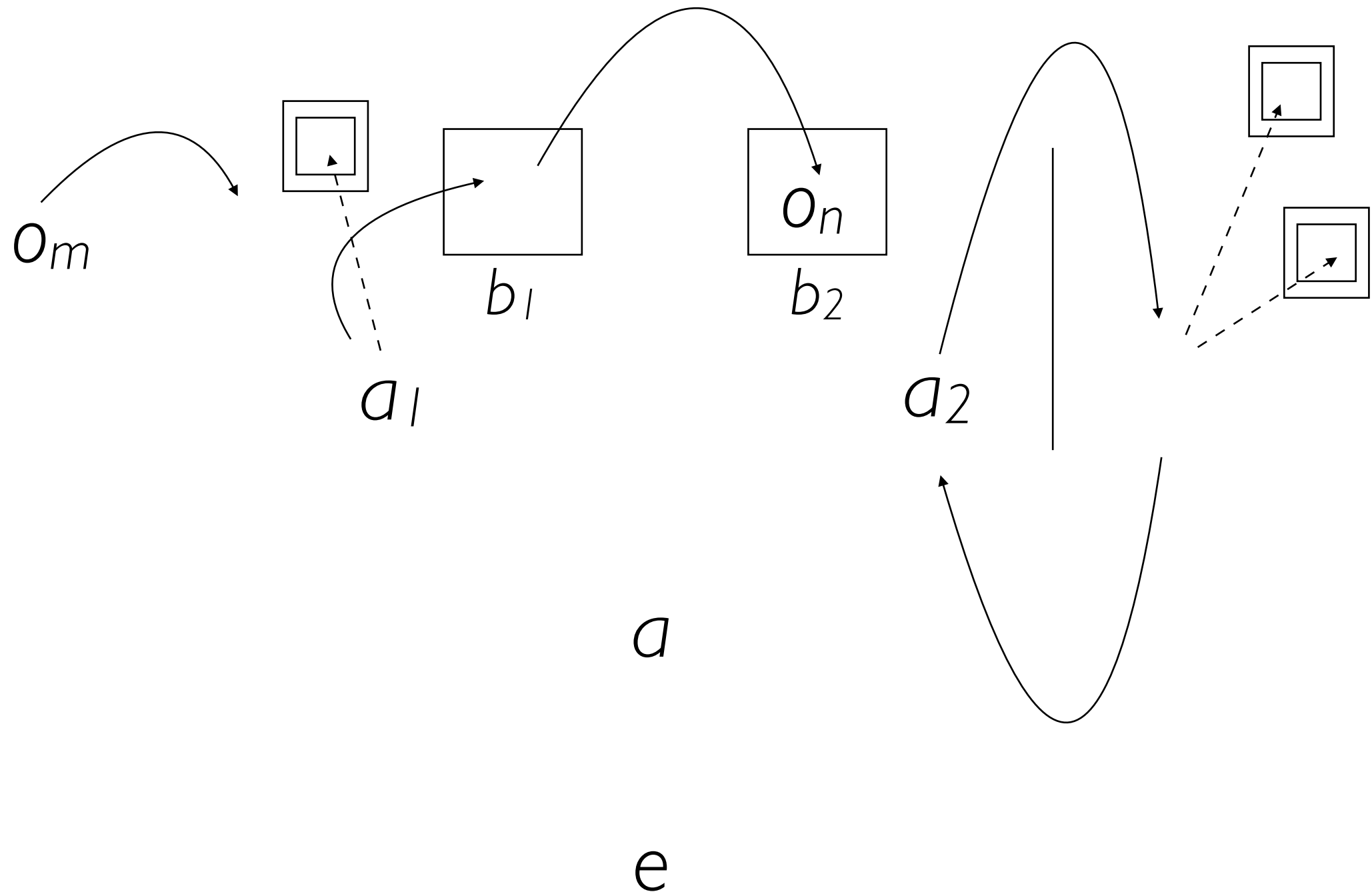
Framework for FBT^I_4

(nine timepoints)



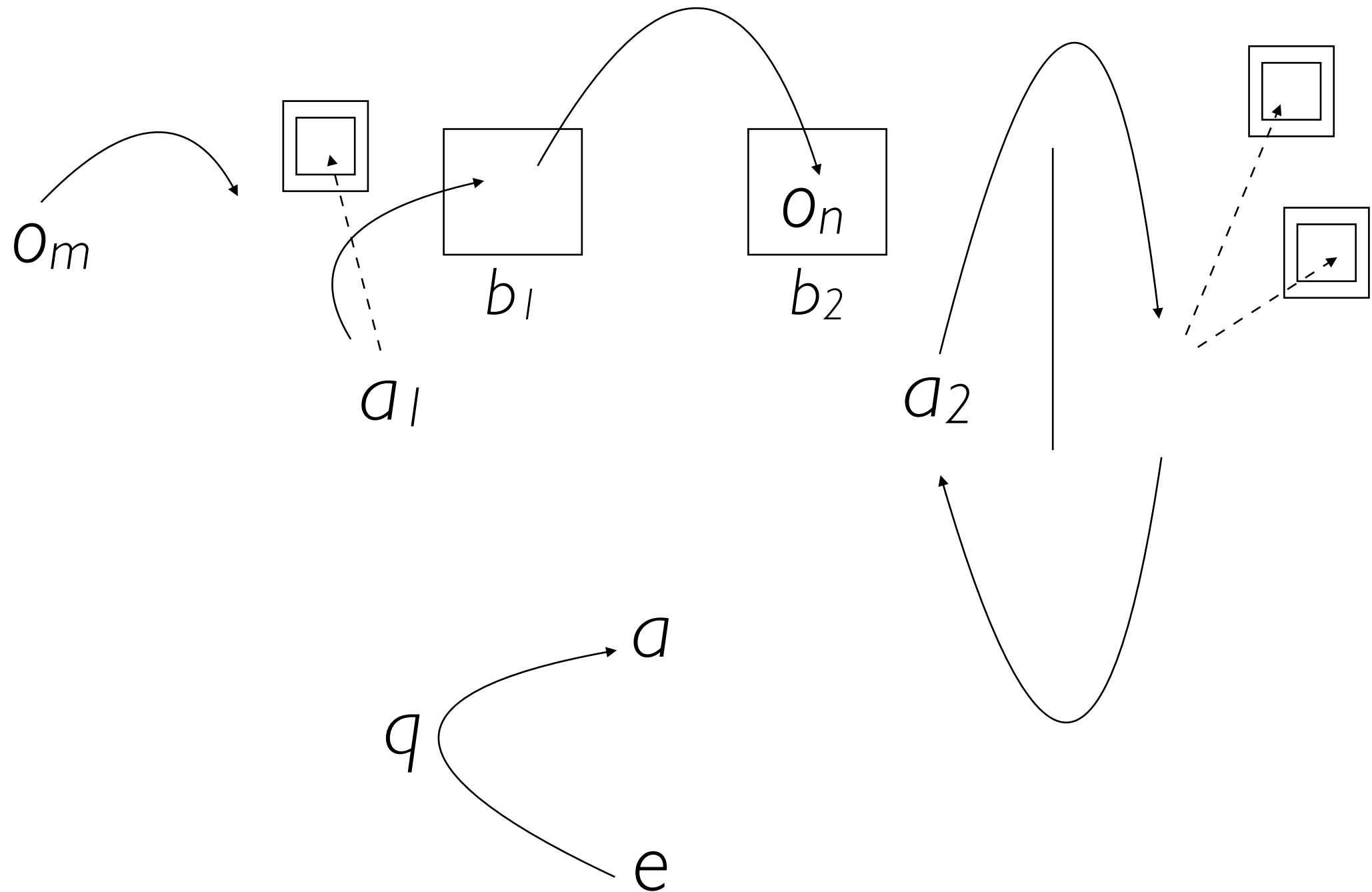
Framework for FBT^I_4

(nine timepoints)



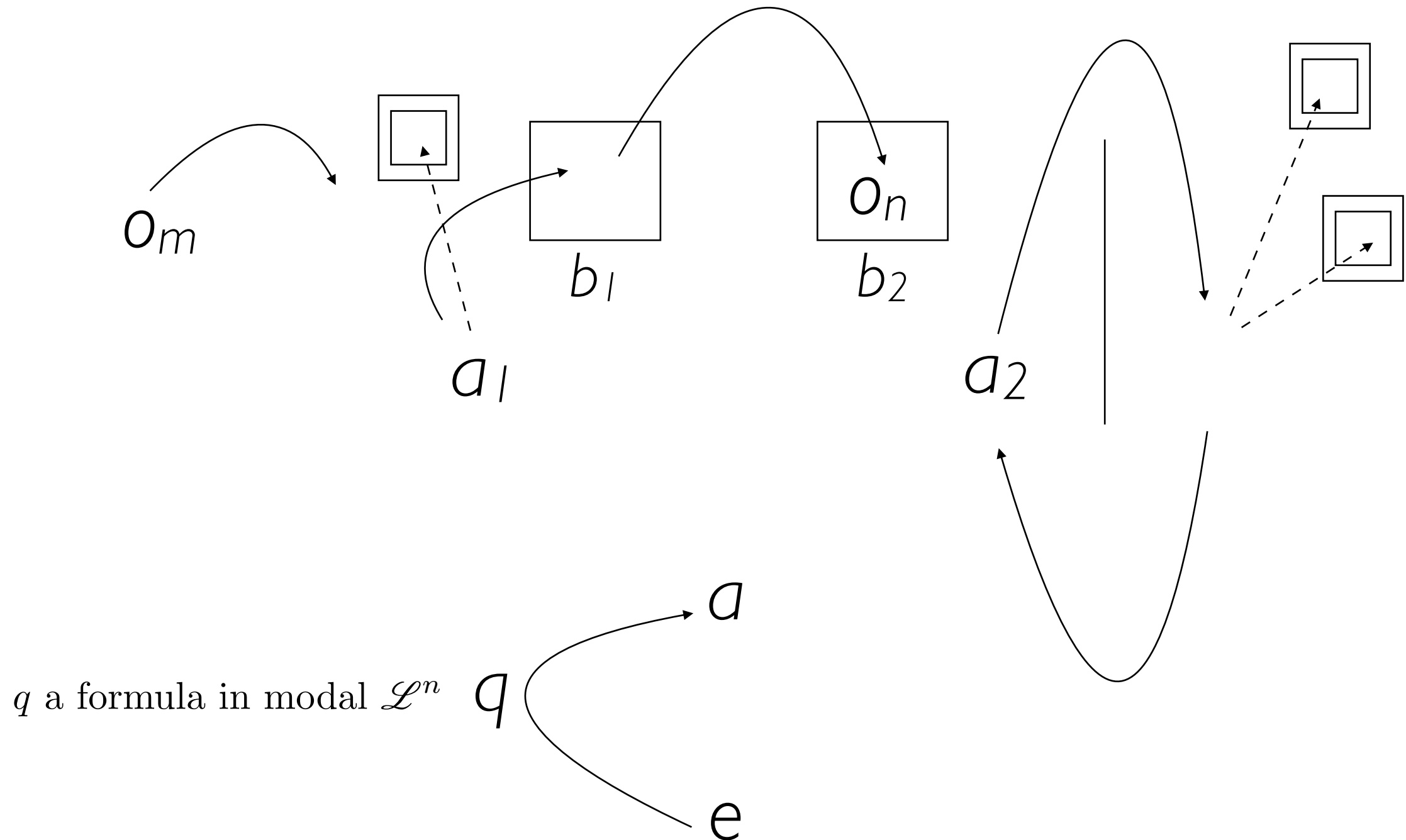
Framework for FBT^I_4

(nine timepoints)

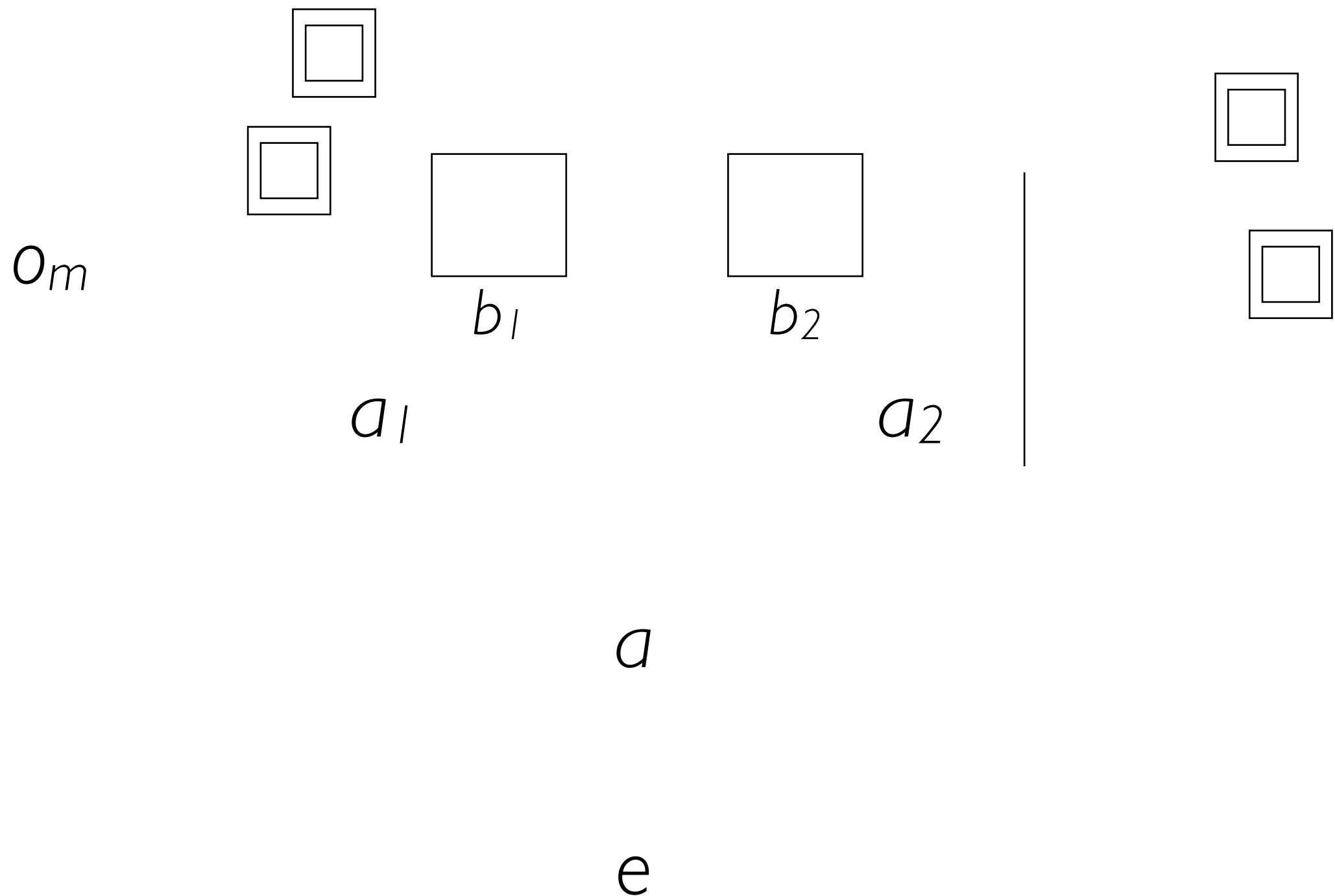


Framework for FBT^I_4

(nine timepoints)

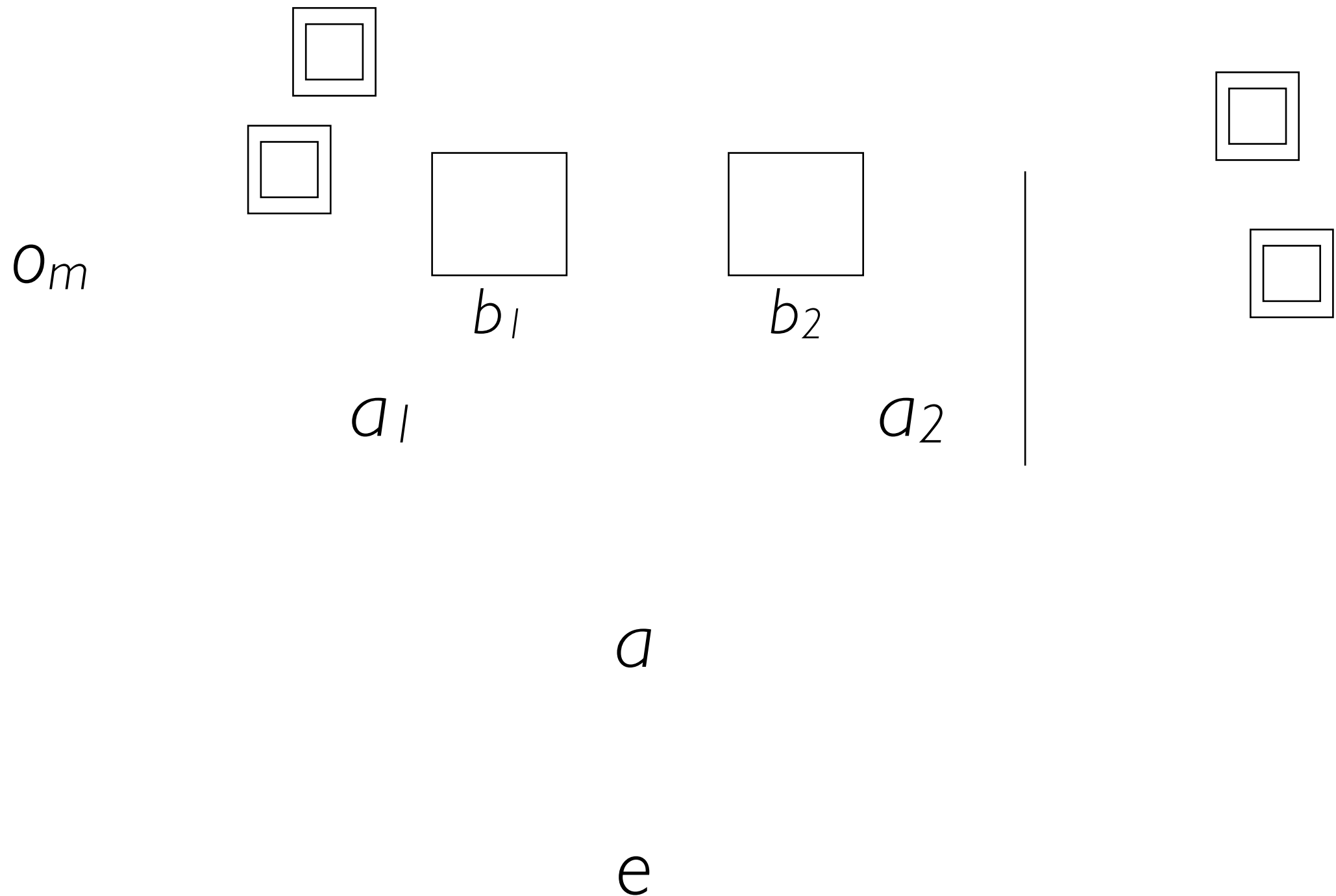


Framework for FBT^I_5



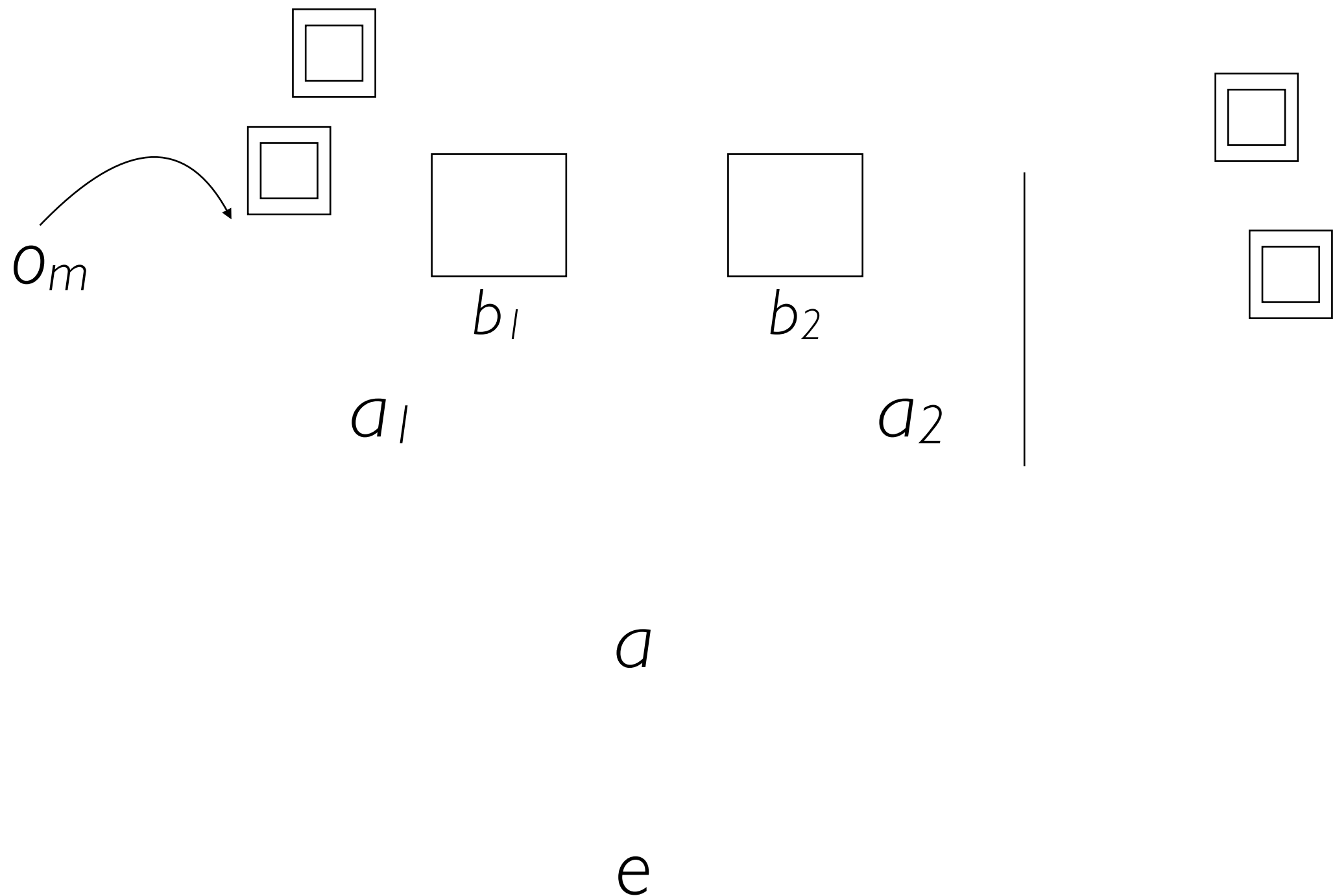
Framework for FBT^I_5

(ten timepoints)



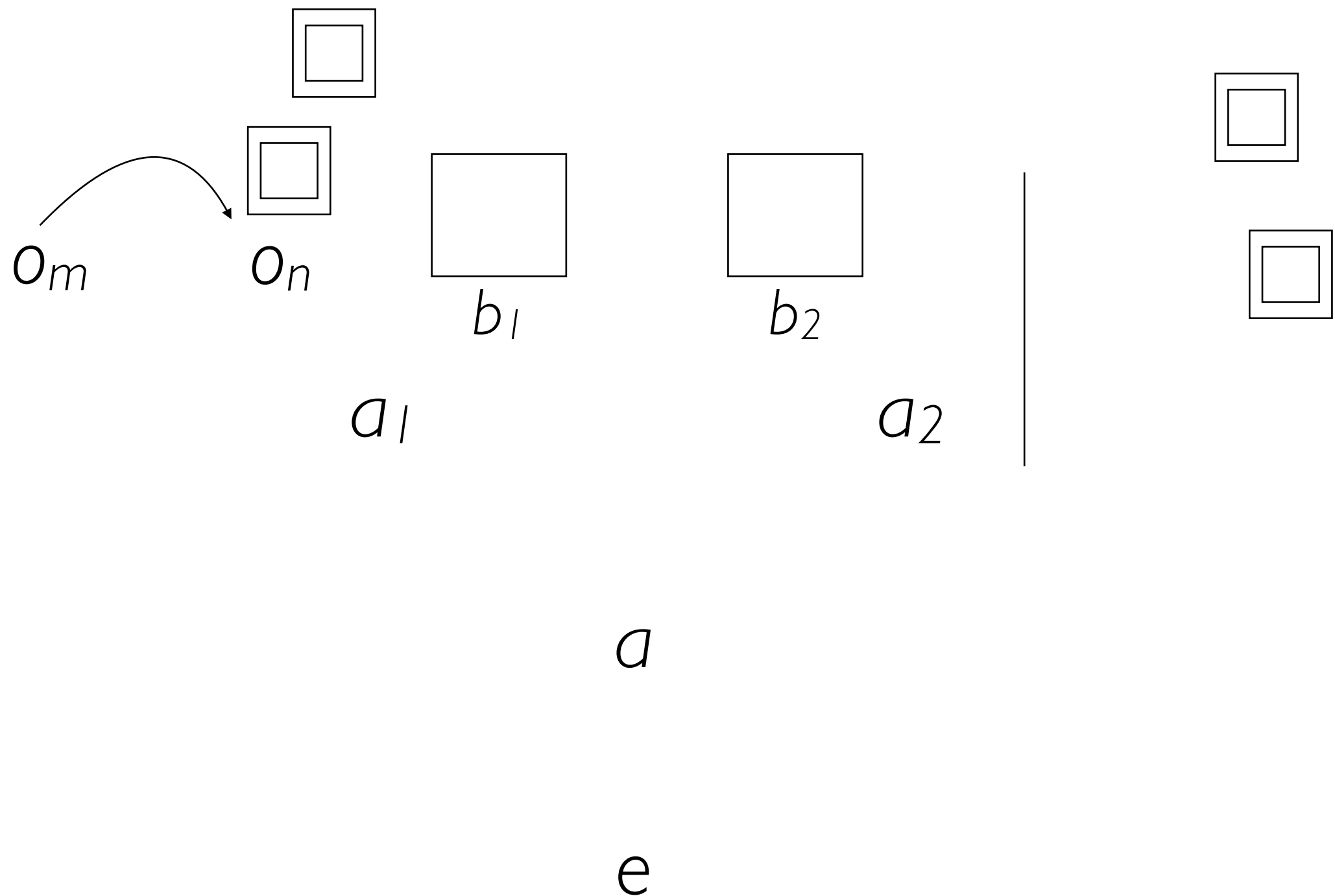
Framework for FBT^I_5

(ten timepoints)



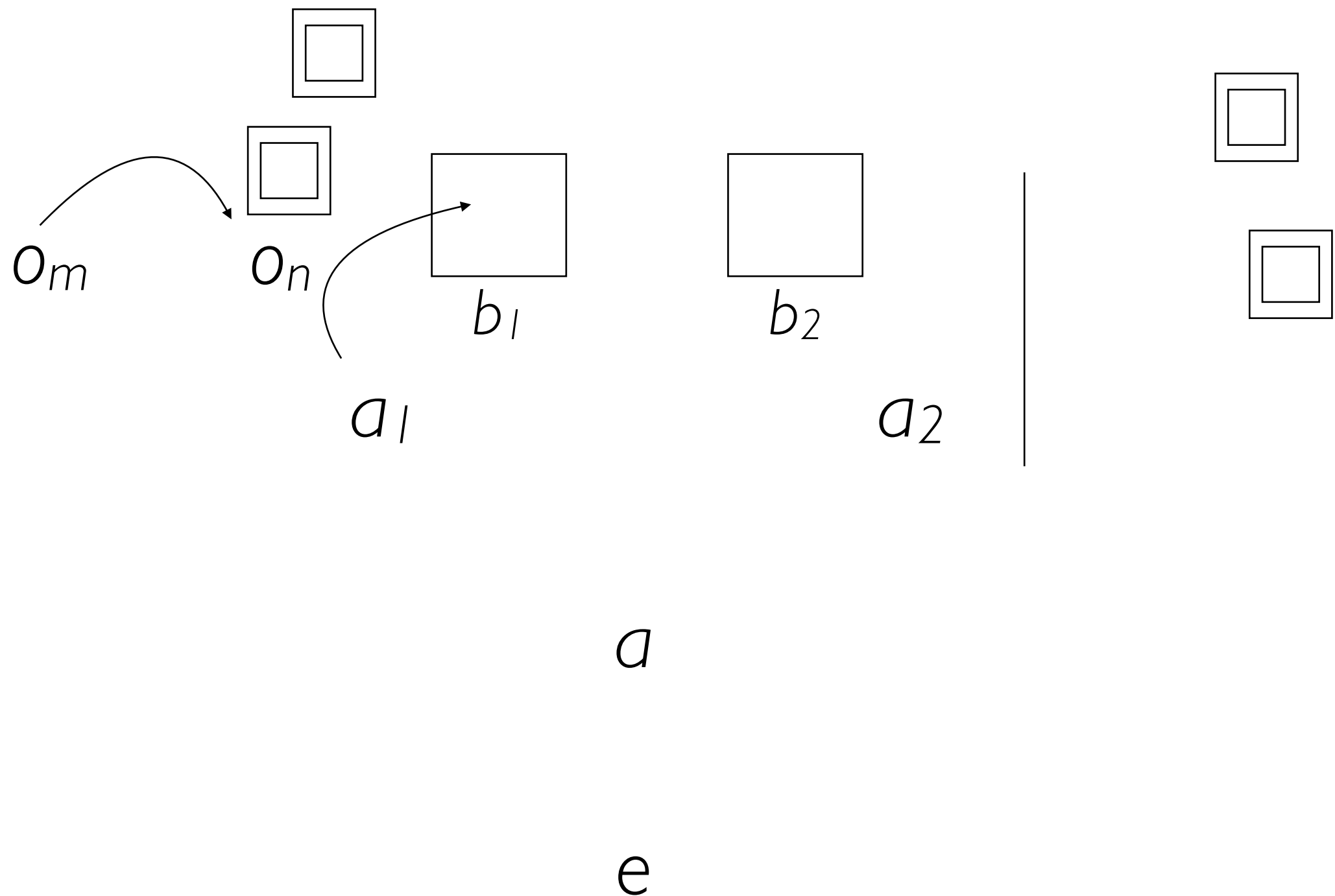
Framework for FBT^I₅

(ten timepoints)



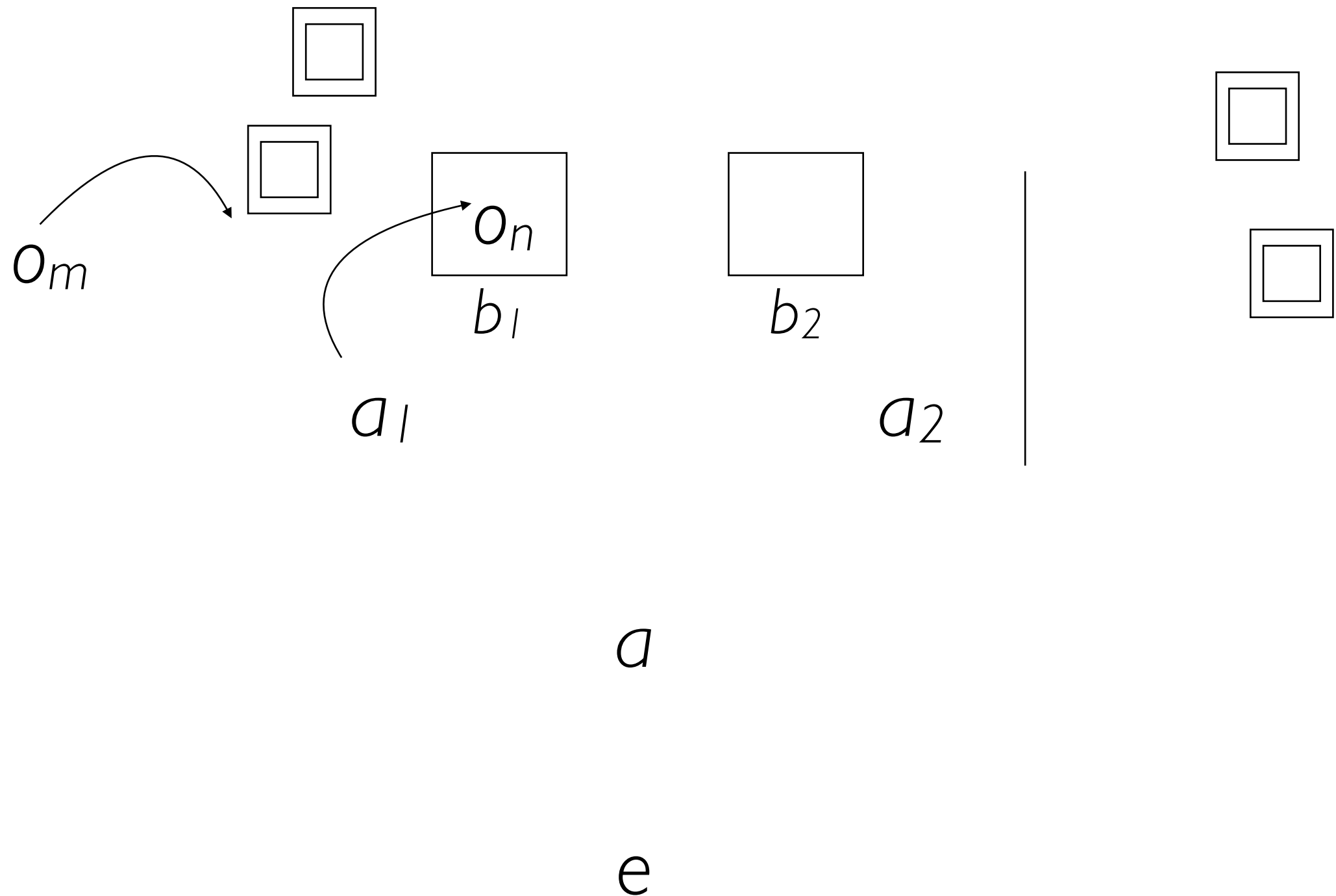
Framework for FBT^I_5

(ten timepoints)



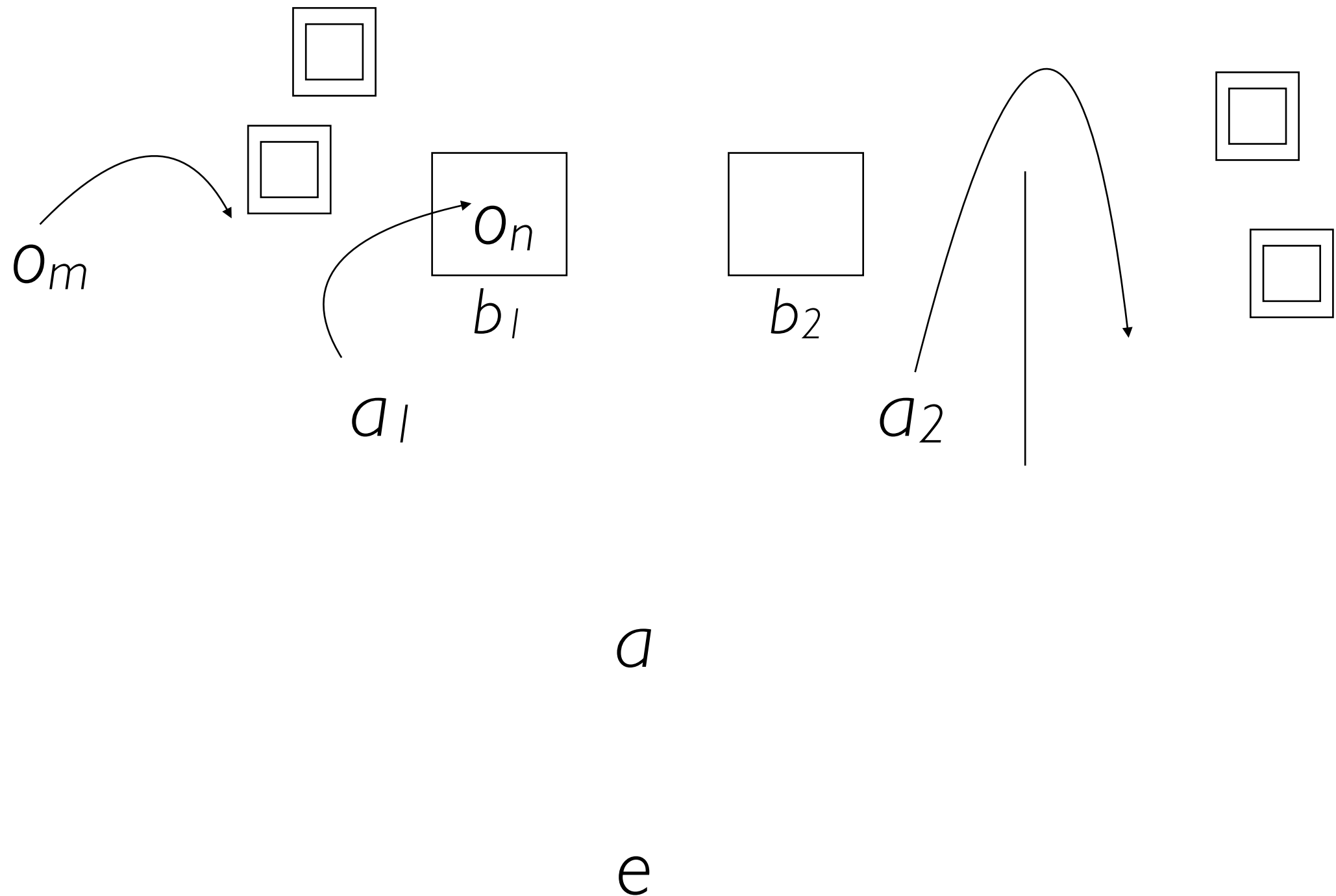
Framework for FBT^I_5

(ten timepoints)



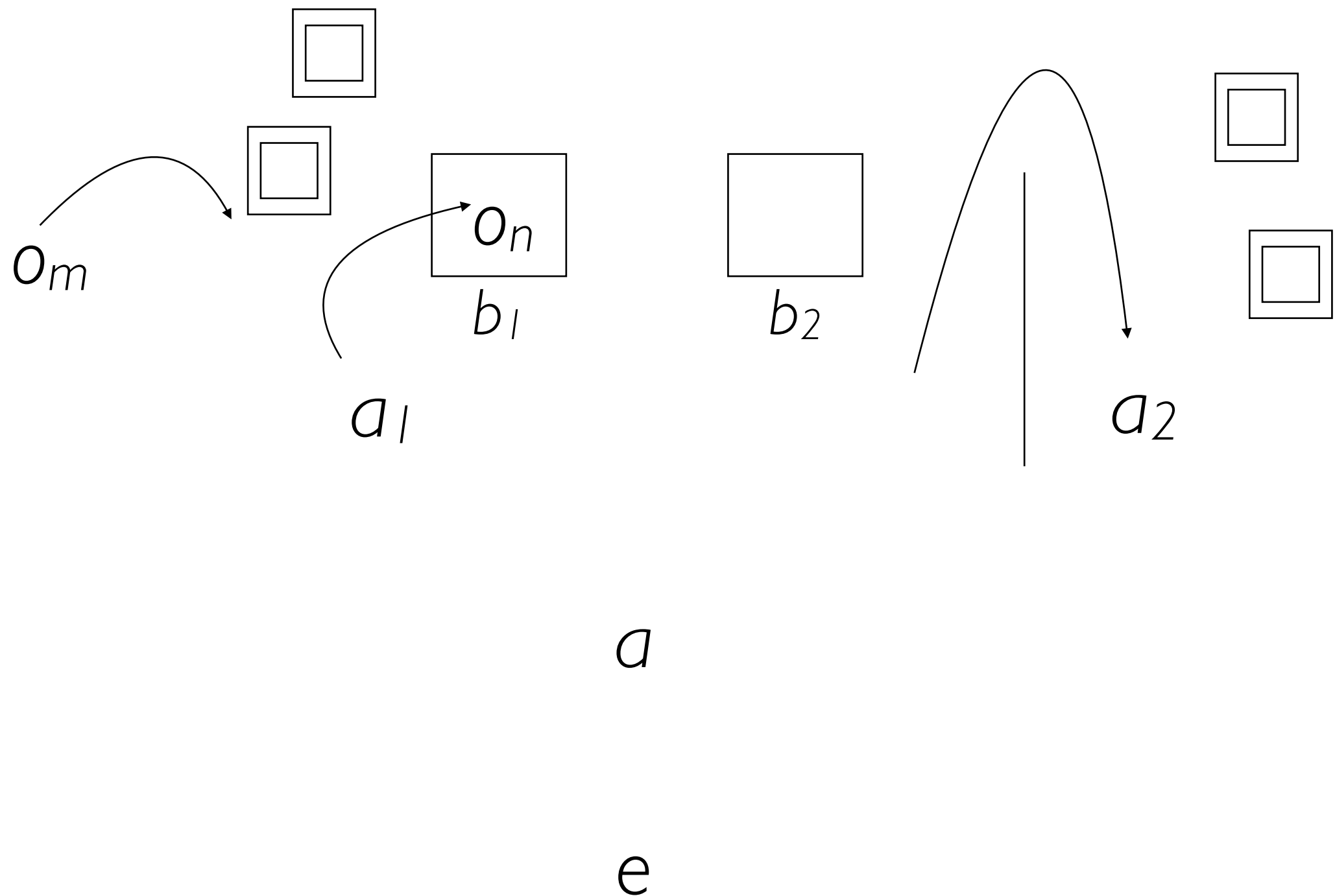
Framework for FBT^I_5

(ten timepoints)



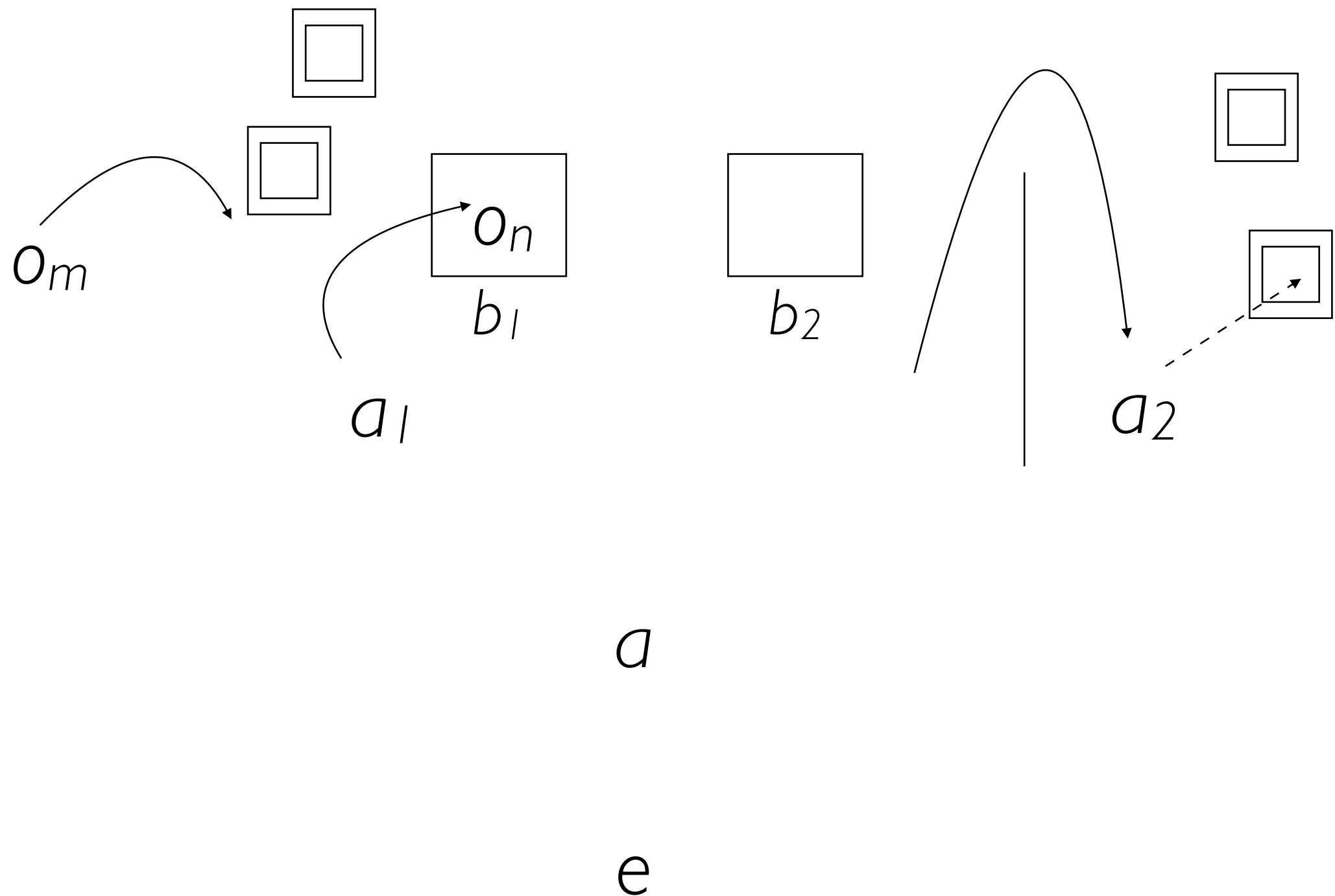
Framework for FBT^I_5

(ten timepoints)



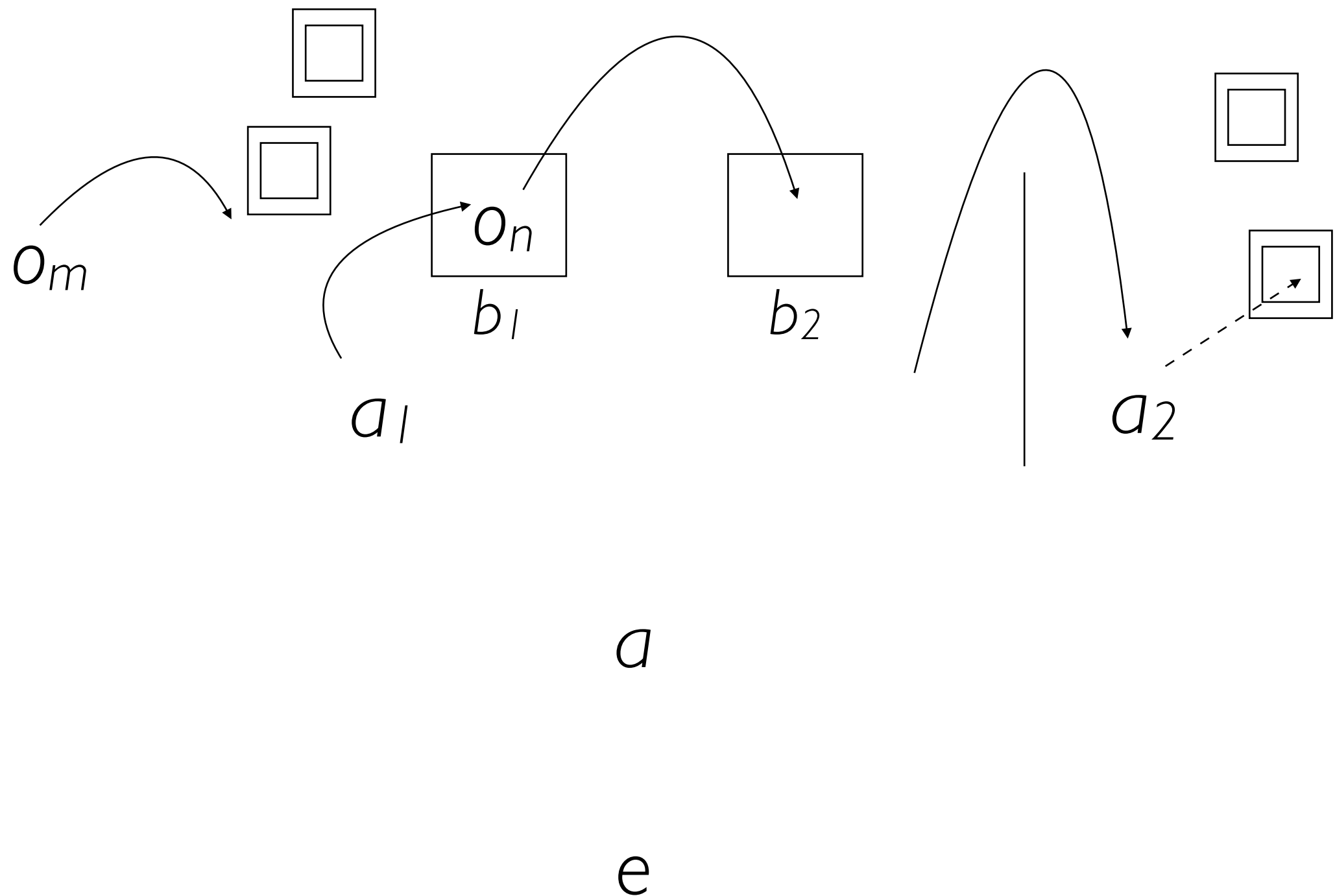
Framework for FBT^I_5

(ten timepoints)



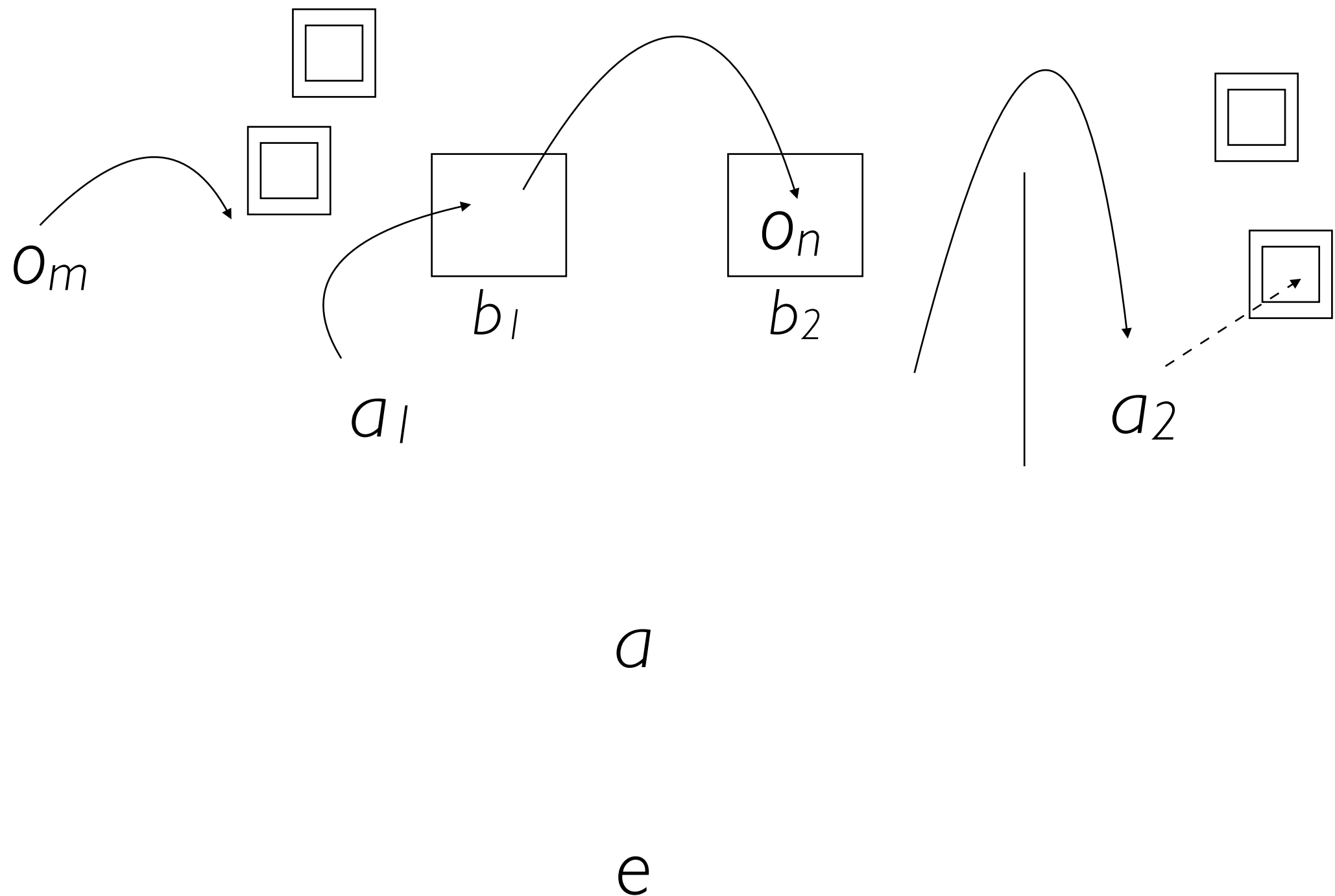
Framework for FBT^I_5

(ten timepoints)



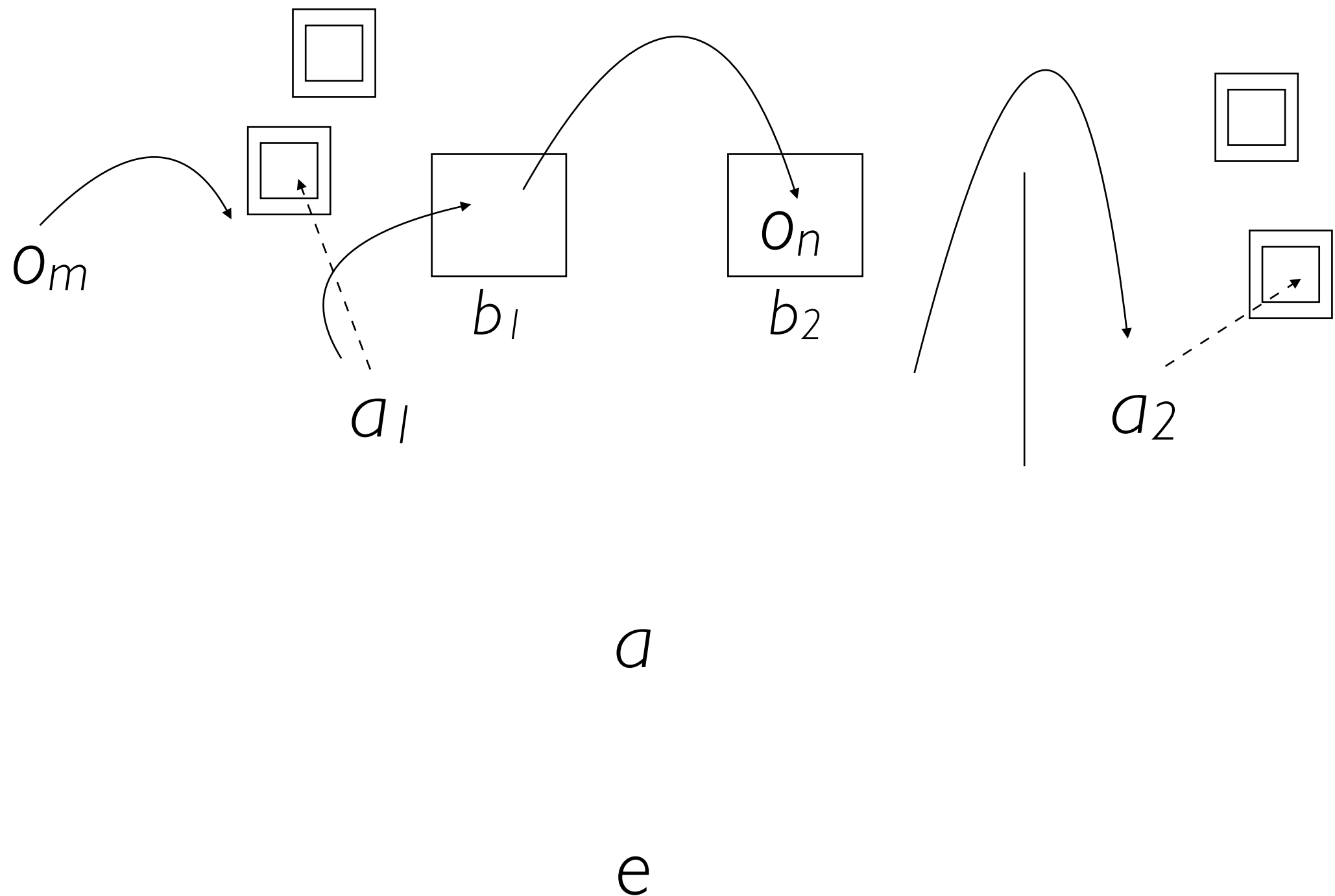
Framework for FBT^I_5

(ten timepoints)



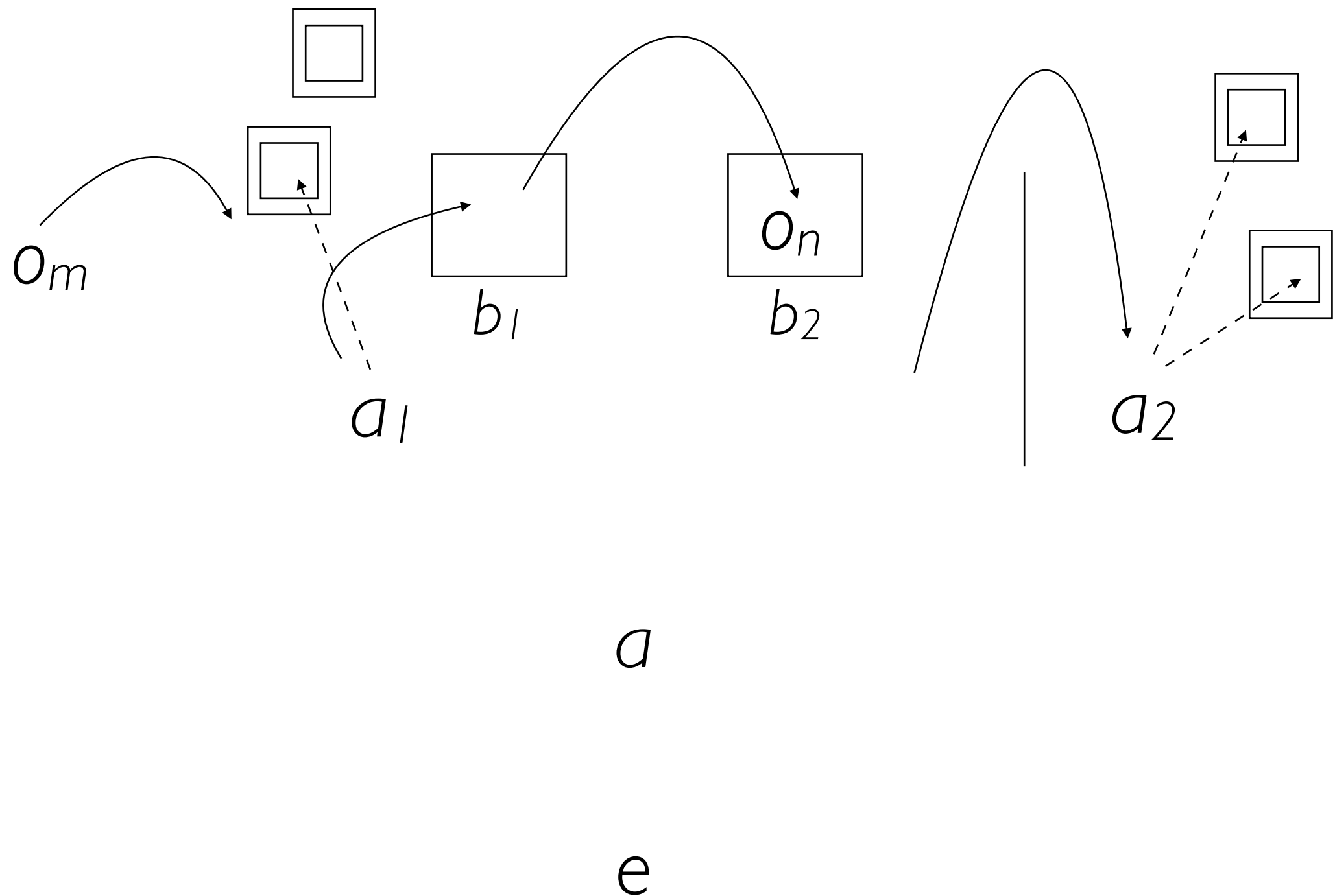
Framework for FBT^I_5

(ten timepoints)



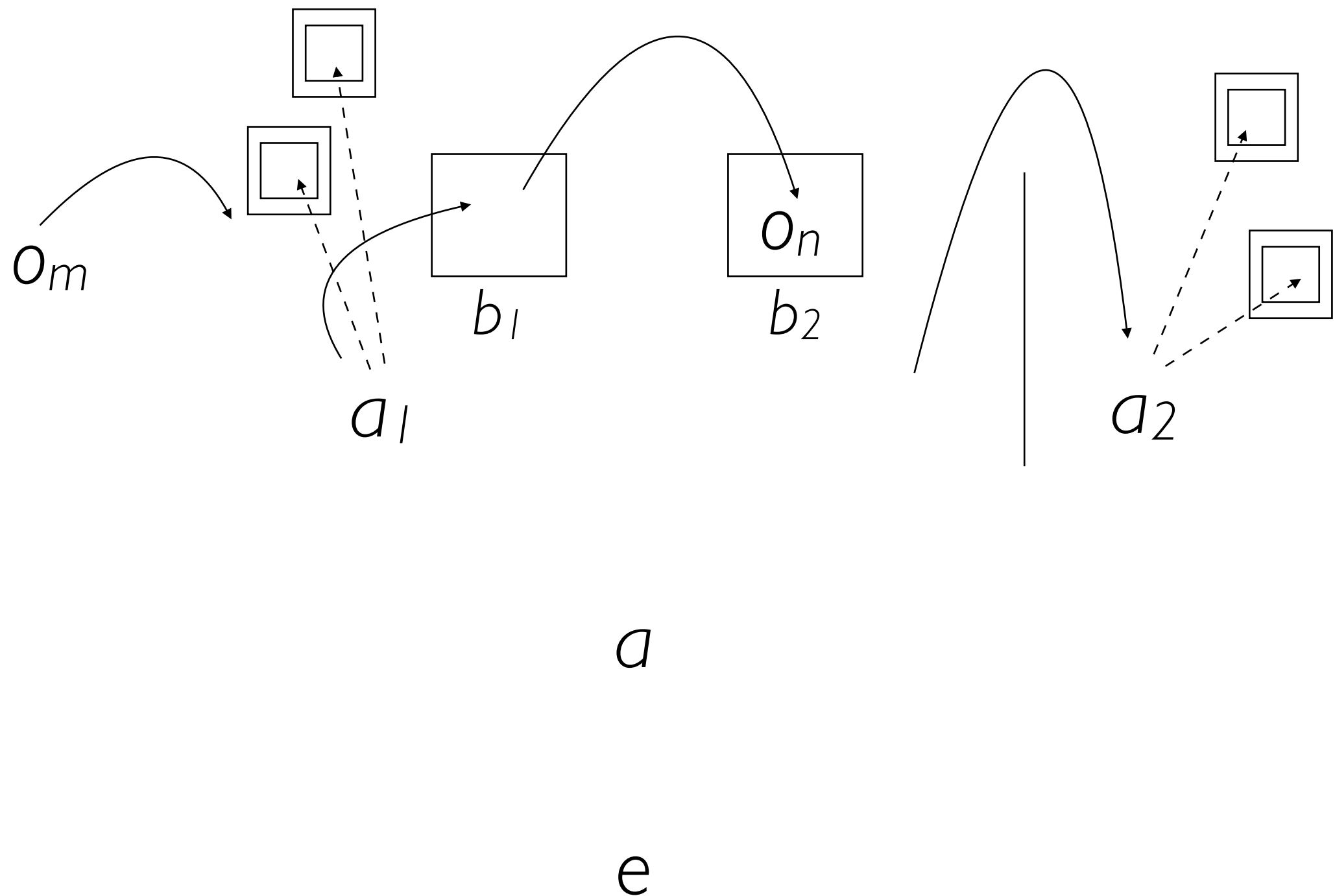
Framework for FBT^I_5

(ten timepoints)



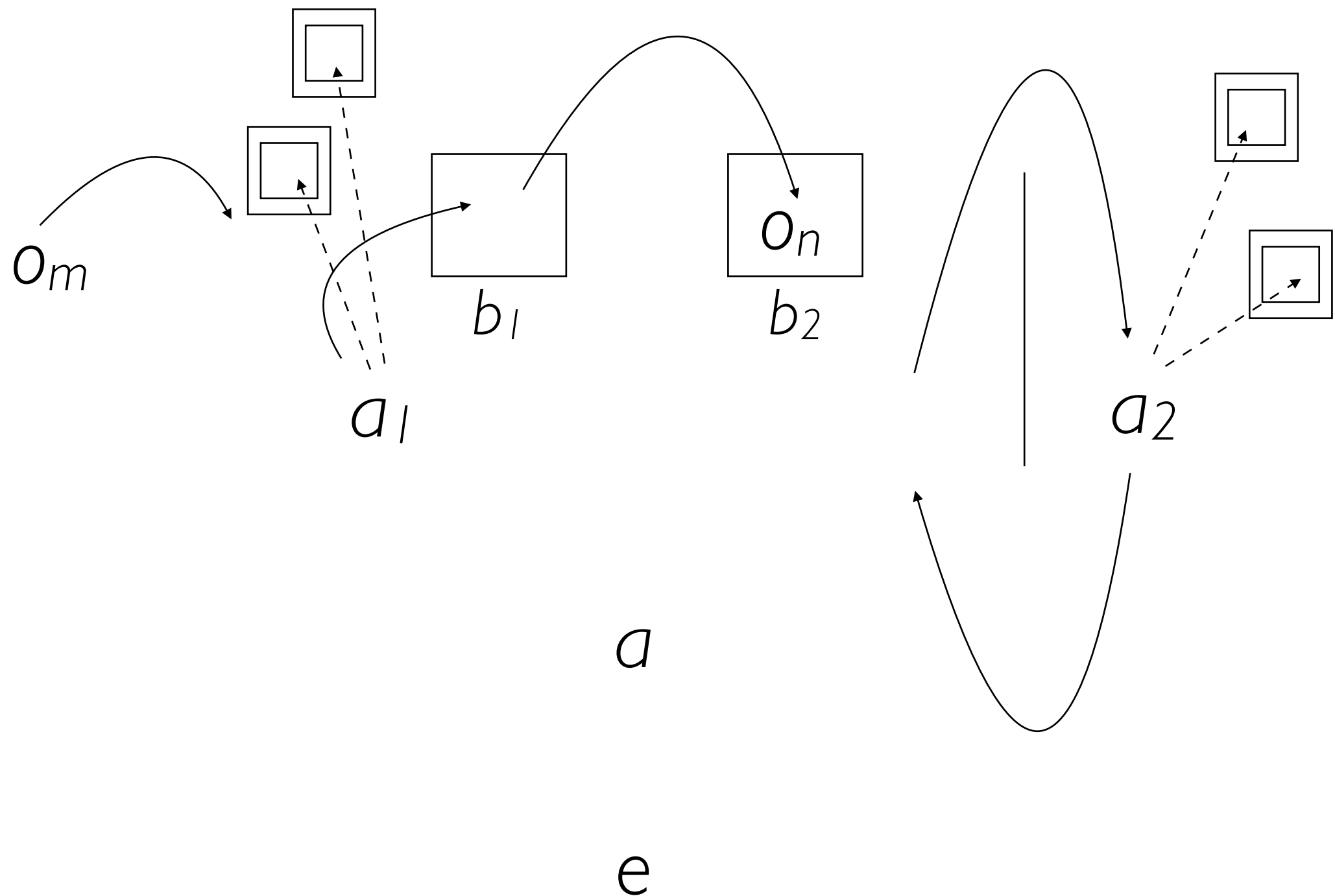
Framework for FBT^I_5

(ten timepoints)



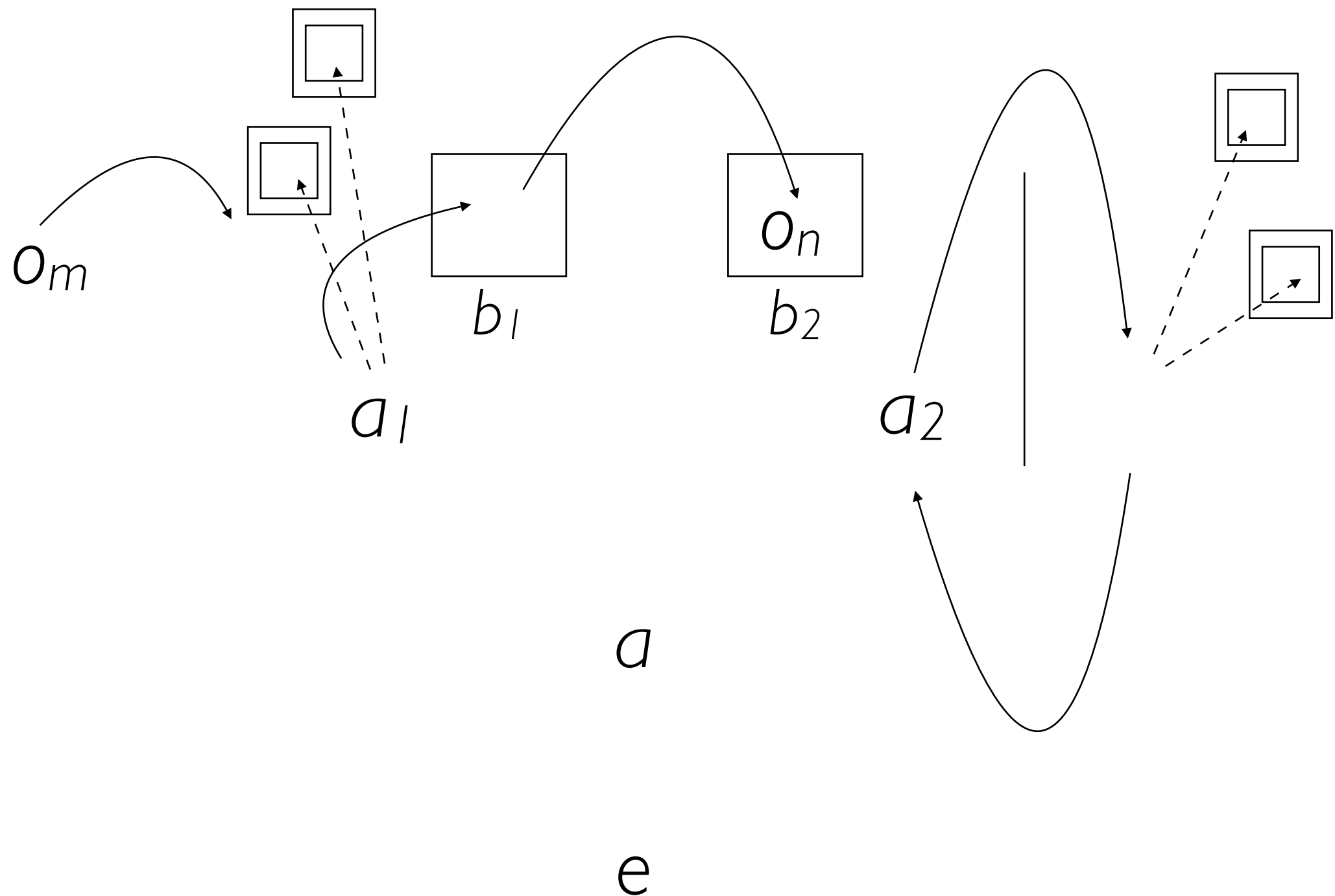
Framework for FBT^I_5

(ten timepoints)



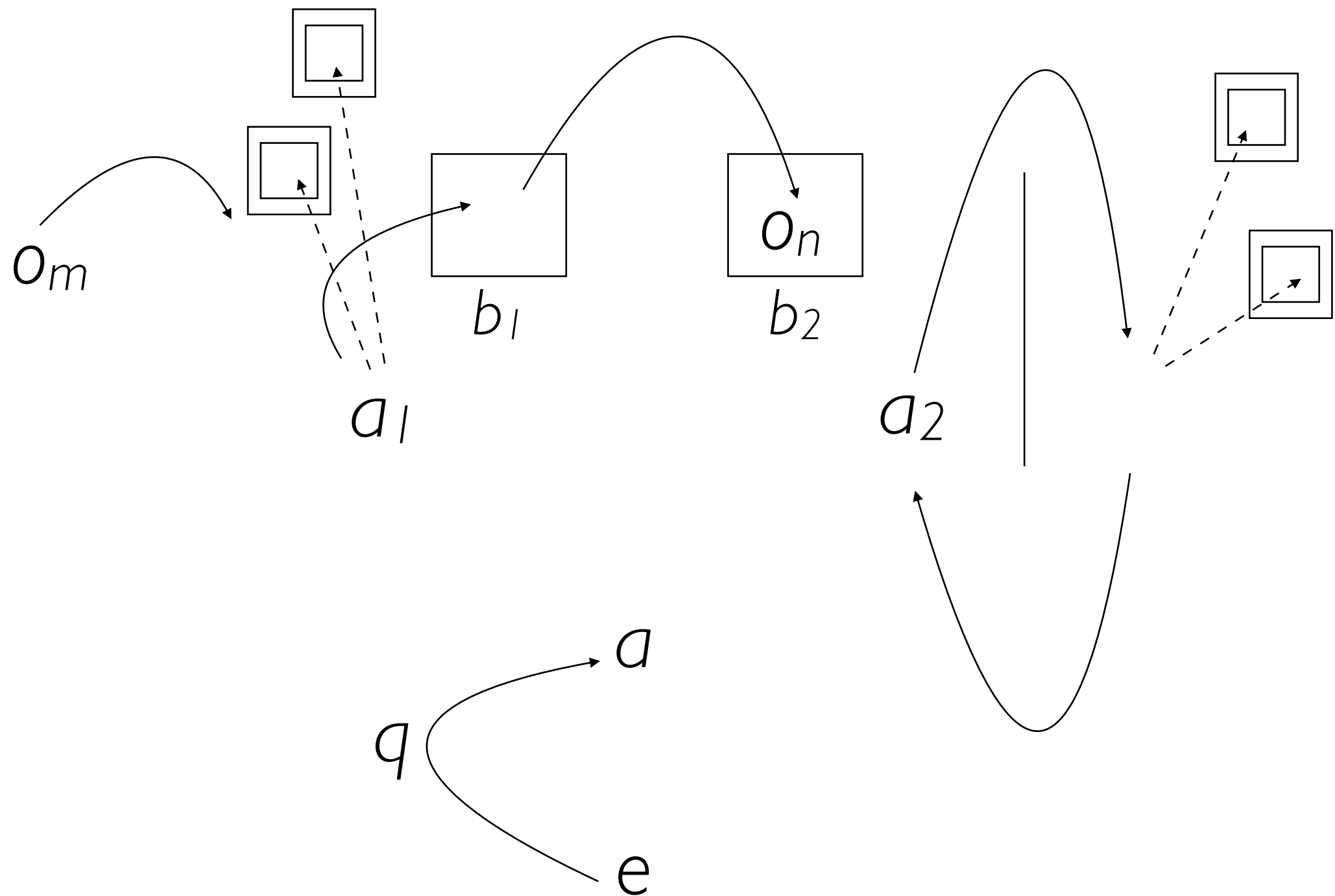
Framework for FBT^I₅

(ten timepoints)

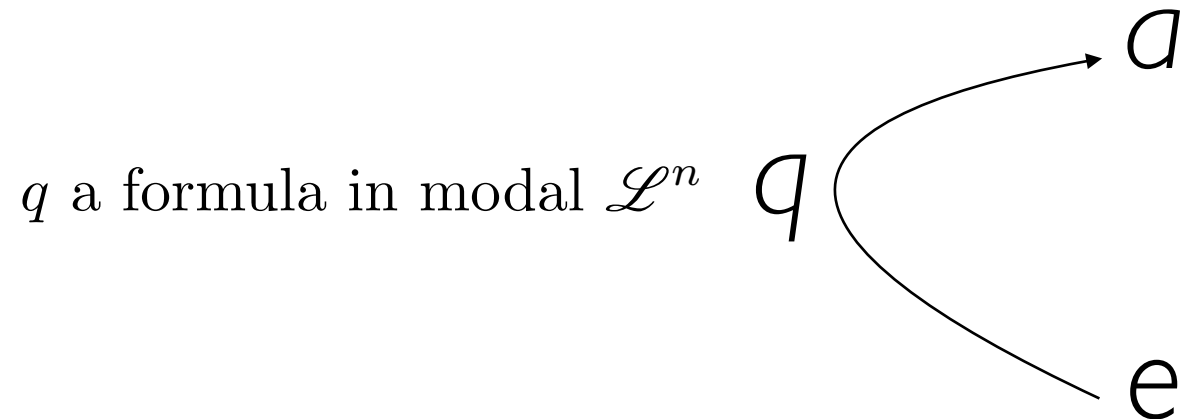


Framework for FBT^I_5

(ten timepoints)



(ten timepoints)



Humans Can Succeed

Neurobiologically normal, nurtured, educated, and sufficiently motivated humans can correctly answer any relevant query q for the infinite progression, and prove that their answer is correct. For the obvious subclass of queries (the form of which appear in the box below), they can prove and exploit the following lemma.

Lemma: Suppose $\text{FBT}_k, k \in \mathbb{Z}^+$, holds; (i.e. that level k of FBT holds). Then, if k is even, $\mathbf{B}_2\mathbf{B}_1 \dots \mathbf{B}_2 \iota$, where there are $k + 1$ iterated \mathbf{B}_i operators; otherwise $\mathbf{B}_1\mathbf{B}_2 \dots \mathbf{B}_1\mathbf{B}_2 \iota$, where there again there are $k + 1$ iterated \mathbf{B}_i operators.

Passing to Probing Mastery of the Specific Subclass

Experimenter to a : “At level k ,
from which box will a_2 attempt to
retrieve the objects o_n ? Prove it!”

Theoretical Machine Success on Infinite FBT!

Theorem: $\forall q \in \mathcal{CC}, \mathfrak{M}$ can correctly answer and justify q .
I.e., \mathfrak{M} can pass FBT_ω .

Ok, so this logic machine exists in the *mathematical* universe; but does there exist an *implemented* machine with this power?

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Ok, so this logic machine exists in the *mathematical* universe; but does there exist an *implemented* machine with this power?

Simulation Courtesy of ...

ShadowProver!



Level I

```
:name      "Level 1: False Belief Task "

:description "Agent a1 puts an object o into b1 in plain view of a2.
Agent a2 then leaves, and in the absence of a2, a1 moves o
from b1 into b2 ; this movement isn't perceived by a2 . Agent
a2 now returns, and a is asked by the experimenter e: "If a2
desires to retrieve o, which box will a2 look in?" If younger
than four or five, a will reply "In b " (which of course fails 2
the task); after this age subjects respond with the correct "In b1."

Level1 Belief: a1 believes a2 believes o is in b1.
"

:date      "Monday July 22, 2019"

:assumptions {
    :P1 (Perceives! a1 t1 (Perceives! a2 t1 (holds (In o b1) t1)))

    :P2 (Believes! a1 t2 (Believes! a2 t2 (not (exists [?e] (terminates ?e (In o b1))))))

    :P3 (holds (In o b1) t1)

    :C1 (Common! t0 (forall [?f ?t2 ?t2]
        (if (and (not (exists [?e] (terminates ?e ?f))) (holds ?f ?t1) (< ?t1 ?t2))
            (holds ?f ?t2))))

    :C2 (Common! t0 (and (< t1 t2) (< t2 t3) (< t1 t3)))
}

:goal      (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))}
```


Level 2

```
{:name      "Level 2: False Belief Task "

:description "Agent a1 puts an object o into b1 in plain view of a2.
Agent a2 then leaves, and in the absence of a2, a1 moves o
from b1 into b2 ; this movement isn't perceived by a2 . Agent
a2 now returns, and a is asked by the experimenter e: "If a2
desires to retrieve o, which box will a2 look in?" If younger
than four or five, a will reply "In b " (which of course fails 2
the task); after this age subjects respond with the correct "In b1."

Level2 Belief: a2 believes a1 believes a2 believes o is in b1.
"

:date      "Monday July 22, 2019"

:assumptions {

    :P1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (holds (In o b1) t1))))

    :P2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (not (exists [?e] (terminates ?e (In o b1)))))))

    :P3 (holds (In o b1) t1)

    :C1 (Common! t0
        (forall [?f ?t2 ?t2]
            (if (and (not (exists [?e] (terminates ?e ?f))) (holds ?f ?t1) (< ?t1 ?t2))
                (holds ?f ?t2))))

    :C2 (Common! t0 (and (< t1 t2) (< t2 t3) (< t1 t3)))

:goal      (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))}
```

Level 3

```
{:name "Level 3: False Belief Task "

:description "Agent a1 puts an object o into b1 in plain view of a2.
Agent a2 then leaves, and in the absence of a2, a1 moves o
from b1 into b2 ; this movement isn't perceived by a2 . Agent
a2 now returns, and a is asked by the experimenter e: "If a2
desires to retrieve o, which box will a2 look in?" If younger
than four or five, a will reply "In b " (which of course fails 2
the task); after this age subjects respond with the correct "In b1."

Level3 Belief: a2 believes a1 believes a2 believes o is in b1.
"

:date "Monday July 22, 2019"

:assumptions {

    :P1 (Perceives! a1 t1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (holds (In o b1) t1))))))
    :P2 (Believes! a1 t2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (not (exists [?e] (terminates ?e (In o b1))))))))))
    :P3 (holds (In o b1) t1)

    :C1 (Common! t0
        (forall [?f ?t2 ?t2]
            (if (and (not (exists [?e] (terminates ?e ?f))) (holds ?f ?t1) (< ?t1 ?t2))
                (holds ?f ?t2))))

    :C2 (Common! t0 (and (< t1 t2) (< t2 t3) (< t1 t3)))}

:goal (Believes! a1 t3 (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))))}
```

Level 4

```
{:name      "Level 4: False Belief Task "

:description "Agent a1 puts an object o into b1 in plain view of a2.
Agent a2 then leaves, and in the absence of a2, a1 moves o
from b1 into b2 ; this movement isn't perceived by a2 . Agent
a2 now returns, and a is asked by the experimenter e: "If a2
desires to retrieve o, which box will a2 look in?" If younger
than four or five, a will reply "In b " (which of course fails 2
the task); after this age subjects respond with the correct "In b1."

Level4 Belief: a2 believes a1 believes a2 believes a1 believes a2 believes o is in b1.
"

:date      "Monday July 22, 2019"

:assumptions {

    :P1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (holds (In o b1) t1))))))
    :P2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (not (exists [?e] (terminates ?e (In o b1))))))))))
    :P3 (holds (In o b1) t1)

    :C1 (Common! t0
        (forall [?f ?t2 ?t2]
            (if (and (not (exists [?e] (terminates ?e ?f))) (holds ?f ?t1) (< ?t1 ?t2))
                (holds ?f ?t2))))

    :C2 (Common! t0 (and (< t1 t2) (< t2 t3) (< t1 t3)))}

:goal      (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))))}
```

Level 5

```
{:name "Level 5: False Belief Task "

:description "Agent a1 puts an object o into b1 in plain view of a2.
Agent a2 then leaves, and in the absence of a2, a1 moves o
from b1 into b2 ; this movement isn't perceived by a2 . Agent
a2 now returns, and a is asked by the experimenter e: "If a2
desires to retrieve o, which box will a2 look in?" If younger
than four or five, a will reply "In b " (which of course fails 2
the task); after this age subjects respond with the correct "In b1."

Level5 Belief: a1 believes a2 believes a1 believes a2 believes a1 believes a2 believes o is in b1.
"

:date "Monday July 22, 2019"

:assumptions {

  :P1 (Perceives! a1 t1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (Perceives! a1 t1 (Perceives! a2 t1 (holds (In o b1) t1)))))))
  :P2 (Believes! a1 t2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (Believes! a1 t2 (Believes! a2 t2 (not (exists [?e] (terminates ?e (In o b1))))))))))
  :P3 (holds (In o b1) t1)

  :C1 (Common! t0
    (forall [?f ?t2 ?t2]
      (if (and (not (exists [?e] (terminates ?e ?f))) (holds ?f ?t1) (< ?t1 ?t2))
        (holds ?f ?t2))))

  :C2 (Common! t0 (and (< t1 t2) (< t2 t3) (< t1 t3)))}

:goal (Believes! a1 t3 (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))))})
```

```

    :goal
      (Common! t0
        (forall [?f ?t2 ?t2]
          (if (and (not (exists [?e] (terminates ?e ?f)))
            (holds ?f ?t1) (< ?t1 ?t2))
            (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))))}

```

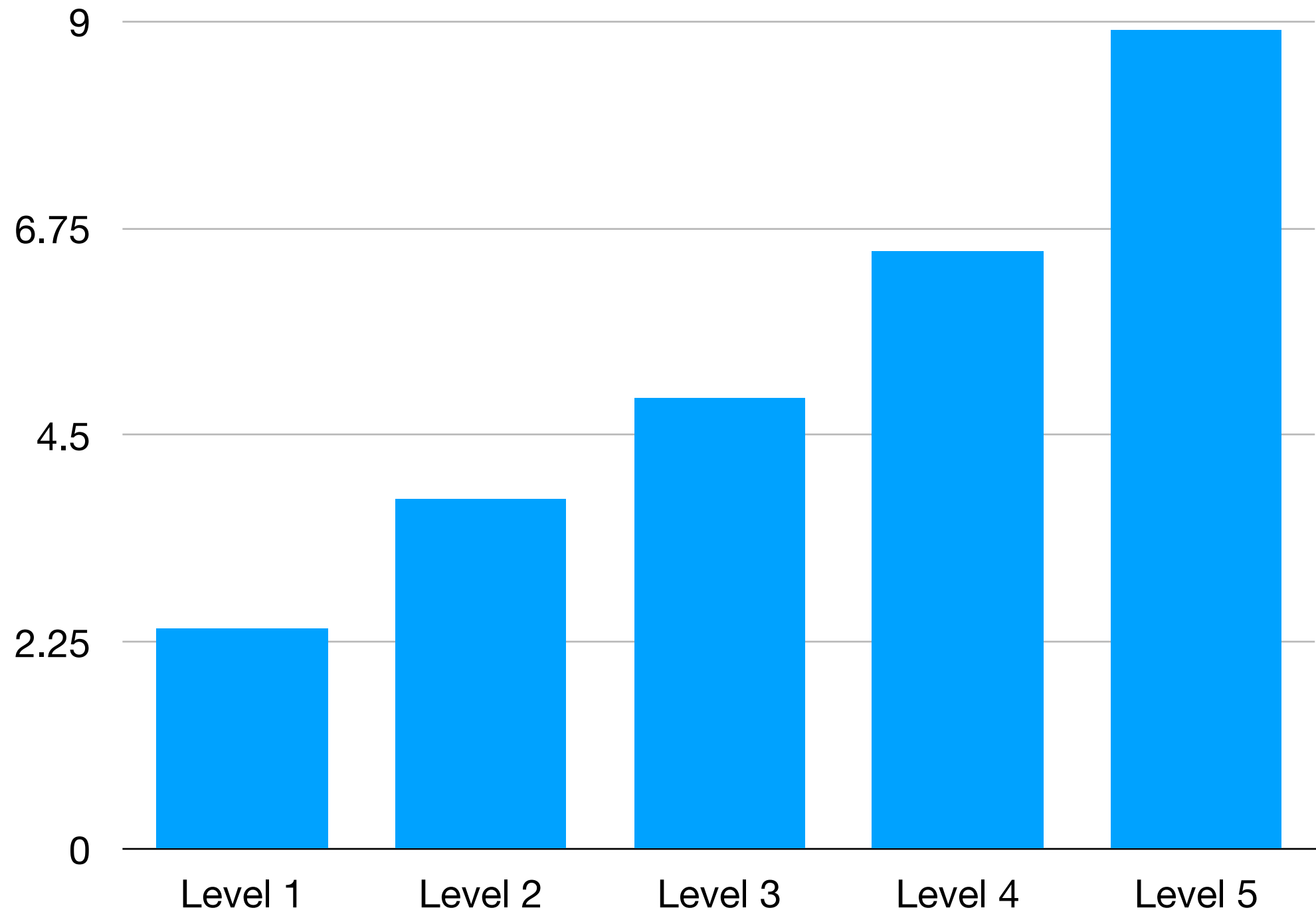


```

    :goal
      (Common! t0
        (forall [?f ?t2 ?t2]
          (if (and (not (exists [?e] (terminates ?e ?f)))
            (holds ?f ?t1) (< ?t1 ?t2))
            (Believes! a1 t3 (Believes! a2 t3 (holds (In o b1) t3))))))}
      )
    )
  )

```

Time (in seconds) to Prove



Simulation of Level 5 in Real Time

```
/Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/bin/java ...  
objc[16653]: Class JavaLaunchHelper is implemented in both /Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/bin/java (0x102a2d4c0) and /Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/jre/lib/libinstrument.dylib (0x102ab94e0)  
----- Level 5 -----
```


Simulation of Level 5 in Real Time

```
/Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/bin/java ...  
objc[16653]: Class JavaLaunchHelper is implemented in both /Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/bin/java (0x102a2d4c0) and /Library/Java/JavaVirtualMachines/jdk1.8.0_131.jdk/Contents/Home/jre/lib/libinstrument.dylib (0x102ab94e0)  
----- Level 5 -----
```

Encapsulation

Slate - K.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
---	---	---	---

Encapsulation

The image shows two overlapping Slate editor windows. The top window is titled 'Slate - K.slt' and contains four boxes with modal logic formulas and their derivability status in the K system. The bottom window is titled 'Slate - T.slt' and contains the same four boxes, but with their derivability status in the T system.

Formula	K System	T System
K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$	$K \vdash \checkmark \infty \Box$	$M \vdash \checkmark \infty \Box$
T. $\Box\varphi \rightarrow \varphi$	$K \vdash \times \infty \Box$	$M \vdash \checkmark \infty \Box$
4. $\Box\varphi \rightarrow \Box\Box\varphi$	$K \vdash \times \infty \Box$	$M \vdash \times \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$	$K \vdash \times \infty \Box$	$M \vdash \times \infty \Box$

Encapsulation

The image displays three overlapping windows, each representing a different modal logic system. Each window contains a grid of boxes, each representing a theorem or axiom and its status in that system. The status is indicated by a checkmark (green) or a cross (red) and the symbol ∞ or \square .

Slate - K.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
---	---	---	---

Slate - T.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
---	---	---	---

Slate - D.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$	

Encapsulation

Slate - K.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
---	---	---	---

Slate - T.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
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Slate - D.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$	

Slate - S4.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ {INTER} Assume \checkmark	

Encapsulation

K

T

D

4 = S4

5 = S5

Slate - K.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
---	---	---	---

Slate - T.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
---	---	---	---

Slate - D.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$	

Slate - S4.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ {INTER} Assume \checkmark	

Slate - S5.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S5 \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $S5 \vdash \checkmark \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ {D} Assume \checkmark	4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ {4} Assume \checkmark
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S5 \vdash \checkmark \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ {INTER} Assume \checkmark	

Encapsulation

K

T

D

4 = S4

5 = S5

The image shows a software interface with five windows, each displaying logical formulas and their derivability status. The windows are titled "Slate - K.slt", "Slate - T.slt", "Slate - D.slt", "Slate - S4.slt", and "Slate - S5.slt".

Slate - K.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$

Slate - T.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$

Slate - D.slt (highlighted with a red border)

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$

Slate - S4.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$

Slate - S5.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S5 \vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$ $S5 \vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$ $\{D\} \text{ Assume } \checkmark$
- 4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $\{4\} \text{ Assume } \checkmark$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S5 \vdash \checkmark \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$

Encapsulation

K
T
D
4 = S4
5 = S5

The screenshot displays five windows of the HyperSlate interface, each representing a different modal logic system. Each window contains a grid of logical formulas and their derivability status (K, T, D, 4, 5) relative to the system's axioms.

- Slate - K.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
- Slate - T.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
- Slate - D.slt** (Highlighted with a red border)
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$
- Slate - S4.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$
- Slate - S5.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S5 \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $S5 \vdash \checkmark \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $\{D\} \text{ Assume } \checkmark$
 - 4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $\{4\} \text{ Assume } \checkmark$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S5 \vdash \checkmark \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$

Review: Encapsulation

K

T

D

4 = S4

5 = S5

Slate - K.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
---	---	---	---

Slate - T.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$	5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
---	---	---	---

Slate - D.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$	

Slate - S4.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$	4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ {INTER} Assume ✓	

Slate - S5.slt

K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S5 \vdash \checkmark \infty \Box$	T. $\Box\varphi \rightarrow \varphi$ $S5 \vdash \checkmark \infty \Box$	D. $\Box\varphi \rightarrow \Diamond\varphi$ {D} Assume ✓	4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ {4} Assume ✓
5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S5 \vdash \checkmark \infty \Box$		INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ {INTER} Assume ✓	

Review: Encapsulation

K

T

D

4 = S4

5 = S5

The screenshot displays five windows from the HyperSlate application, each showing a set of modal logic formulas and their status in a specific logic.

- Slate - K.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $K \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $K \vdash \times \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $K \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $K \vdash \times \infty \Box$
- Slate - T.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $M \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $M \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $M \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $M \vdash \times \infty \Box$
- Slate - D.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $D \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $D \vdash \times \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $D \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $D \vdash \times \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $D \vdash \times \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $D \vdash \checkmark \infty \Box$
- Slate - S4.slt** (highlighted with a red border)
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S4 \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $S4 \vdash \checkmark \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $S4 \vdash \checkmark \infty \Box$
 - 4. $\Box\varphi \rightarrow \Box\Box\varphi$ $S4 \vdash \checkmark \infty \Box$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S4 \vdash \times \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$
- Slate - S5.slt**
 - K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $S5 \vdash \checkmark \infty \Box$
 - T. $\Box\varphi \rightarrow \varphi$ $S5 \vdash \checkmark \infty \Box$
 - D. $\Box\varphi \rightarrow \Diamond\varphi$ $\{D\} \text{ Assume } \checkmark$
 - 4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$ $\{4\} \text{ Assume } \checkmark$
 - 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$ $S5 \vdash \checkmark \infty \Box$
 - INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$ $\{INTER\} \text{ Assume } \checkmark$

Review: Encapsulation

K

T

D

4 = S4

5 = S5

The screenshot displays the HyperSlate interface with several windows showing logic calculi and their axioms/inference rules.

Slate - K.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
K $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
K $\vdash \times \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
K $\vdash \times \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$
K $\vdash \times \infty \Box$

Slate - T.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
- T. $\Box\varphi \rightarrow \varphi$
M $\vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
M $\vdash \times \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$
M $\vdash \times \infty \Box$

Create file

- Propositional Calculus
- L_0 = Pure Predicate Calculus
- L_1 = First-order Logic
- L_2 = Second-order Logic
- K
- T
- D
- S4
- S5
- DCEC (fragment)
- Hyperlog

Slate - S4.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
S4 $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
S4 $\vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$
S4 $\vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
S4 $\vdash \checkmark \infty \Box$
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$
S4 $\vdash \times \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$
{INTER} Assume \checkmark

Slate - S5.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
S5 $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
S5 $\vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$
{D} Assume \checkmark
- 4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
{4} Assume \checkmark
- 5. $\neg\Box\varphi \rightarrow \Box\neg\Box\varphi$
S5 $\vdash \checkmark \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$
{INTER} Assume \checkmark

Review: Encapsulation

K

T

D

4 = S4

5 = S5

The screenshot displays the HyperSlate interface with several windows showing different modal logics. The 'Create file' menu is highlighted with a green box, and the 'K' option is selected. The S4 and S5 calculi windows are highlighted with a red box.

Slate - K.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
K $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
K $\vdash \times \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
K $\vdash \times \infty \Box$
- 5. $\Box\varphi \rightarrow \Box\neg\Box\varphi$
K $\vdash \times \infty \Box$

Slate - T.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
- T. $\Box\varphi \rightarrow \varphi$
M $\vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
M $\vdash \times \infty \Box$
- 5. $\Box\varphi \rightarrow \Box\neg\Box\varphi$
M $\vdash \times \infty \Box$

Create file

- Propositional Calculus
- L_0 = Pure Predicate Calculus
- L_1 = First-order Logic
- L_2 = Second-order Logic
- K**
- T
- D
- S4
- S5

Slate - S4.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
S4 $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
S4 $\vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$
S4 $\vdash \checkmark \infty \Box$
- 4. $\Box\varphi \rightarrow \Box\Box\varphi$
S4 $\vdash \checkmark \infty \Box$
- 5. $\Box\varphi \rightarrow \Box\neg\Box\varphi$
S4 $\vdash \times \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$
{INTER} Assume \checkmark

Slate - S5.slt

- K. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
S5 $\vdash \checkmark \infty \Box$
- T. $\Box\varphi \rightarrow \varphi$
S5 $\vdash \checkmark \infty \Box$
- D. $\Box\varphi \rightarrow \Diamond\varphi$
{D} Assume \checkmark
- 4. $\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi)$
{4} Assume \checkmark
- 5. $\Box\varphi \rightarrow \Box\neg\Box\varphi$
S5 $\vdash \checkmark \infty \Box$
- INTER. $\Box\varphi \leftrightarrow \neg\Diamond\neg\varphi$
{INTER} Assume \checkmark

*Det er en logikk for
hvert problem!*