ALLOY 6

A MATTER OF TIME

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ALLOY 6
Lesson objectives

To understand how Alloy 5 deals with **dynamic modeling**

To understand which are the **limitations** of the **dynamic modeling** in Alloy 5 and why Alloy needed a **new version**

To understand which are the **new features** introduced in **Alloy 6**

STATIC

VS

DYNAMIC

STATIC

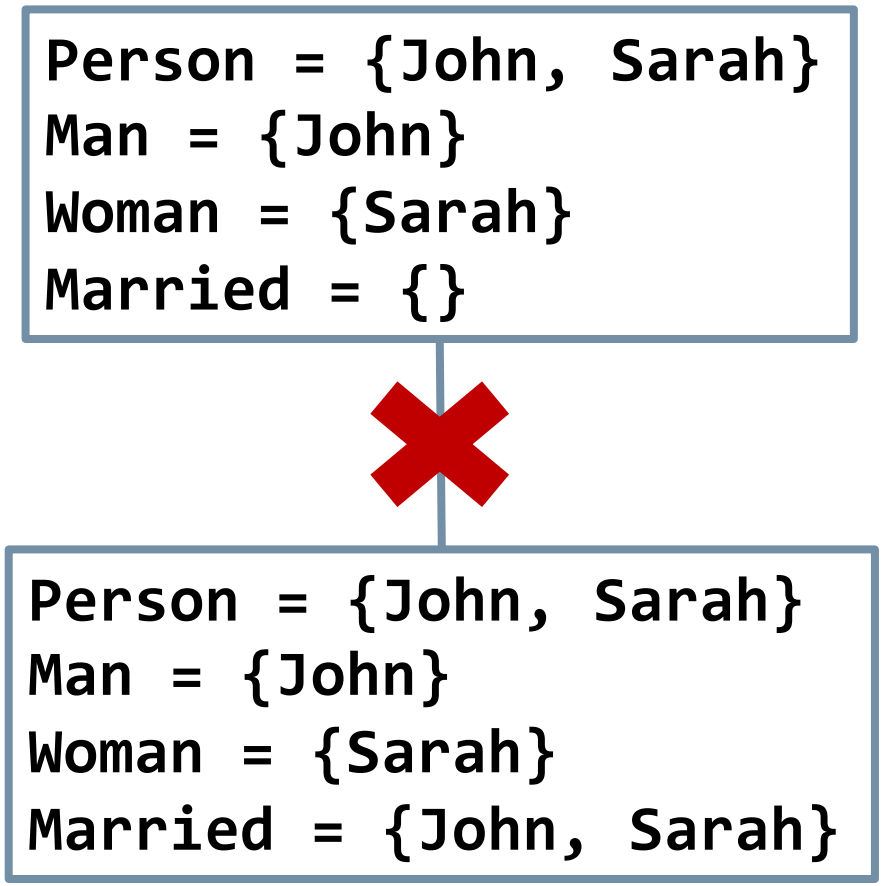
- Represents something that **does not change** over time
- Allows to describe a **legal state** of a dynamic system

```
abstract sig Person {
    father: lone Man,
    mother: lone Woman
}

sig Man extends Person {
    wife: lone Woman
}

sig Woman extends Person {
    husband: lone Man
}
```

STATIC

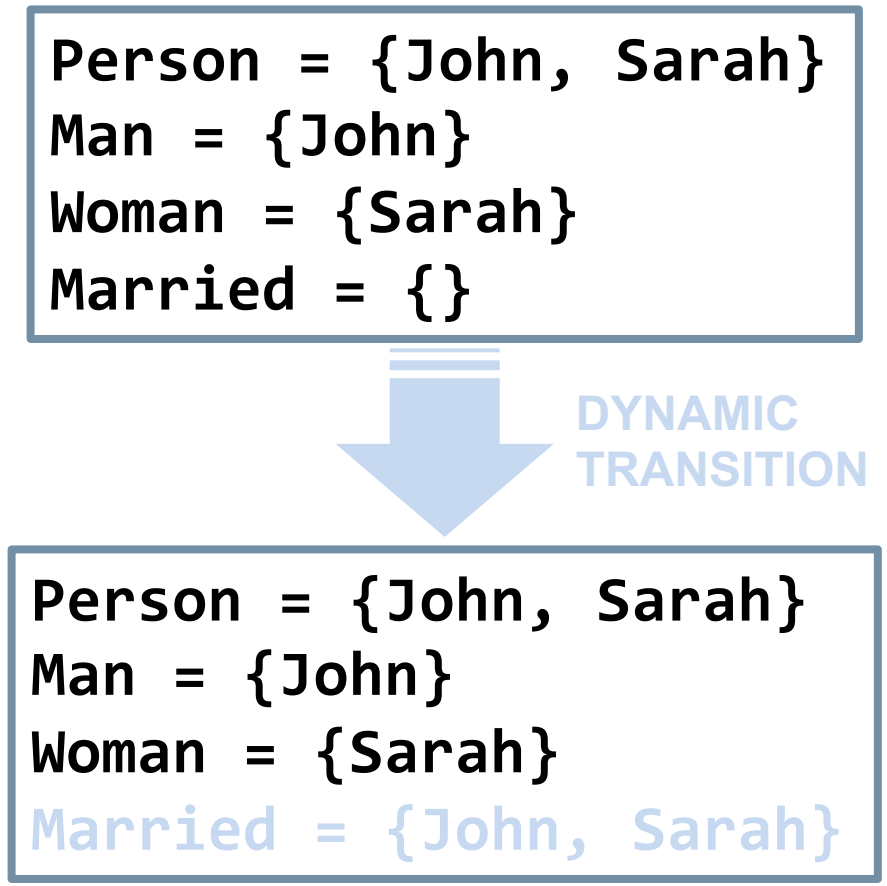
- Represents something that **does not change** over time
- Allows to describe a **legal state** of a dynamic system

STATIC MODEL INSTANCES



DYNAMIC

- Represents something **changing** over time
- Allows to describe possible **transitions between states** of the system



Until Alloy 6: **no** predefined **notion of time** and of state transition

BUT two ways to model dynamic aspects of a system:

1. By placing an **ordering** on some signatures
2. By introducing a **Time signature** expressing time

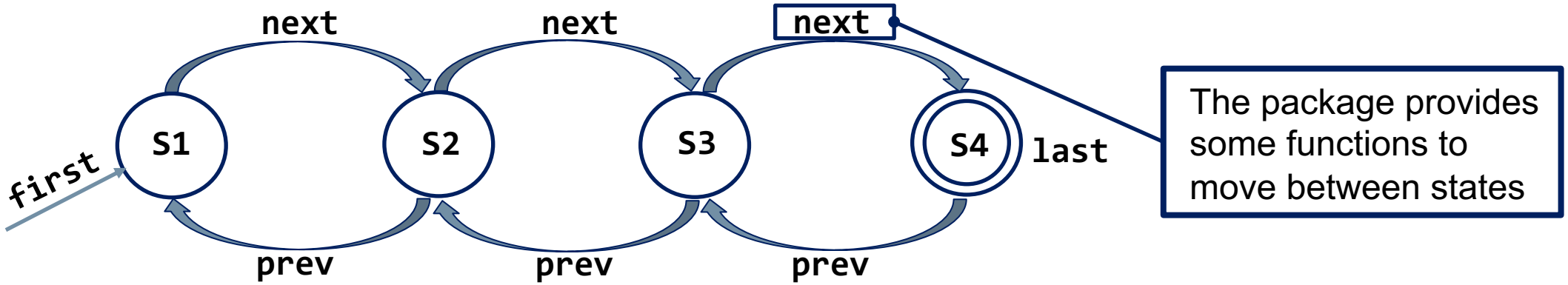
By placing an **ordering** on some signatures

```
open util/ordering[S]
sig S{}
```

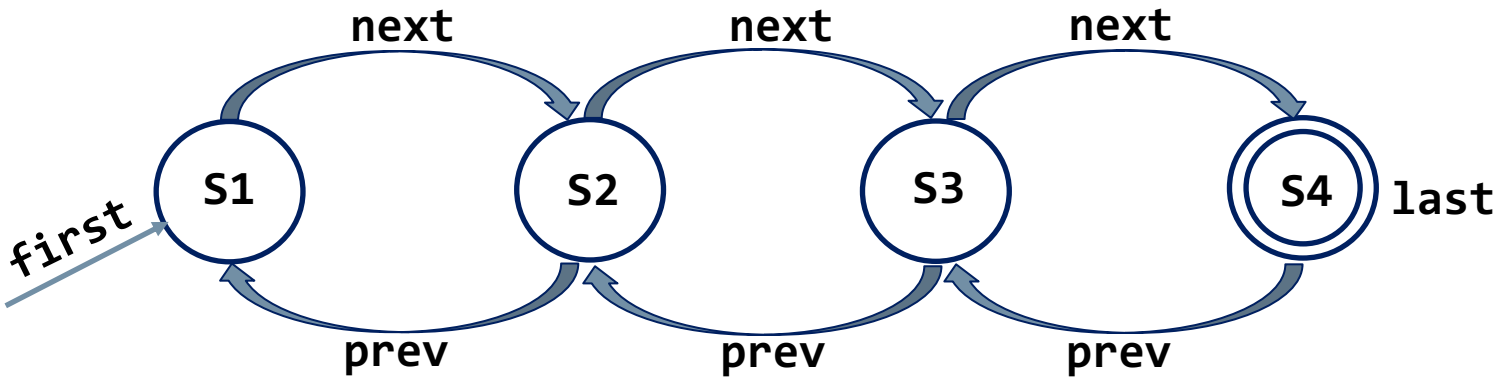
Creates a **single linear ordering** over signature S

- There are **multiple "S" atoms** representing the **same physical element** but **at different points in time**

- It is like creating a **finite state machine** on atoms of "S"



TRACE (Alloy 5): a fact that describes how the system will evolve by constraining "valid models" to ones where the system evolves properly




```
open util/ordering[S] as ord
…
fact traces {
    ord/first=S1
    all s: ord-ord/last |
    let s' = s.next |
    // general operations
    op1[s, s'] or … or opN[s, s']
}
```

The ordering method is really **hard to use** when we have **multiple** signatures that are changing or multiple properties that can change:

- We should **place the order on each signature** that can change over time
- → the code is not optimized

…WE CAN DO BETTER!

Until Alloy 6: **no** predefined **notion of time** and of state transition

BUT two ways to model dynamic aspects of a system:

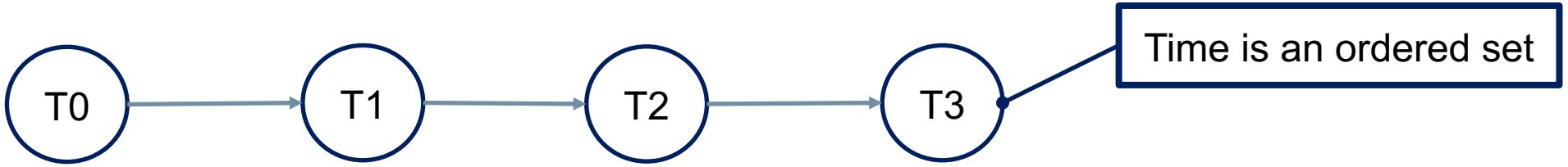
1. By placing an **ordering** on some signatures
2. By introducing a **Time signature** expressing time

by introducing a **Time signature** expressing time

```
open util/ordering[Time]
sig Time {}
```

Creates a **Time signature** that internally uses the ordering module

- The **linear ordering** is placed **on Time**



- We have to add a **time component** to each **relation** that **changes** over time

DYNAMIC

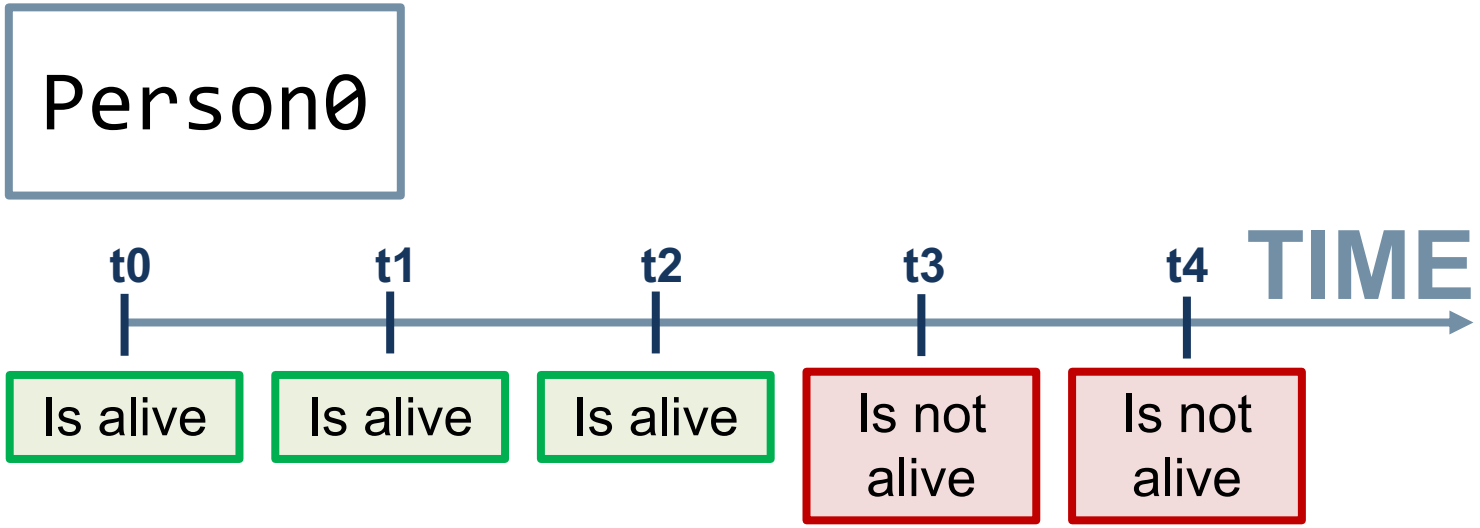
- Represents something **changing** over time
- Allows to describe possible **transitions between states** of the system

```
sig Time {}

abstract sig Person {
    father: Man
    mother: Woman
    alive: set Time
}

sig Man extends Person {
    wife: Woman lone -> Time
}

sig Woman extends Person {
    husband: Man lone -> Time
}
```

If the **relation** that changes over time is **BOOLEAN**:

```
sig Person {
   alive: set Time
}
```

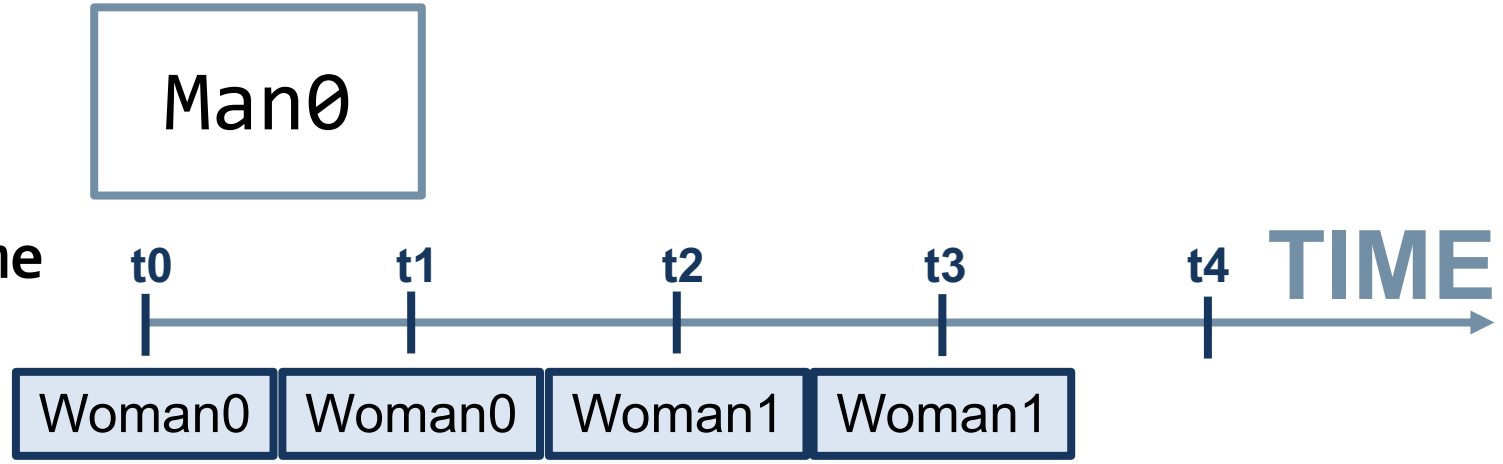
times where the field is true



If the **relation** that changes over time is **ARBITRARY**:

```
sig Man extends Person {
   wife: Woman lone -> Time
}
```

Multirelation with time:
for every Man and Time,
there is at most one Woman



There are **some limitations** to what we can model in a dynamic system:

- Import a package and try to **emulate** time without dealing with a **real** notion of **time**
- Alloy cannot test that some property is guaranteed to happen in infinite time (**liveness)**

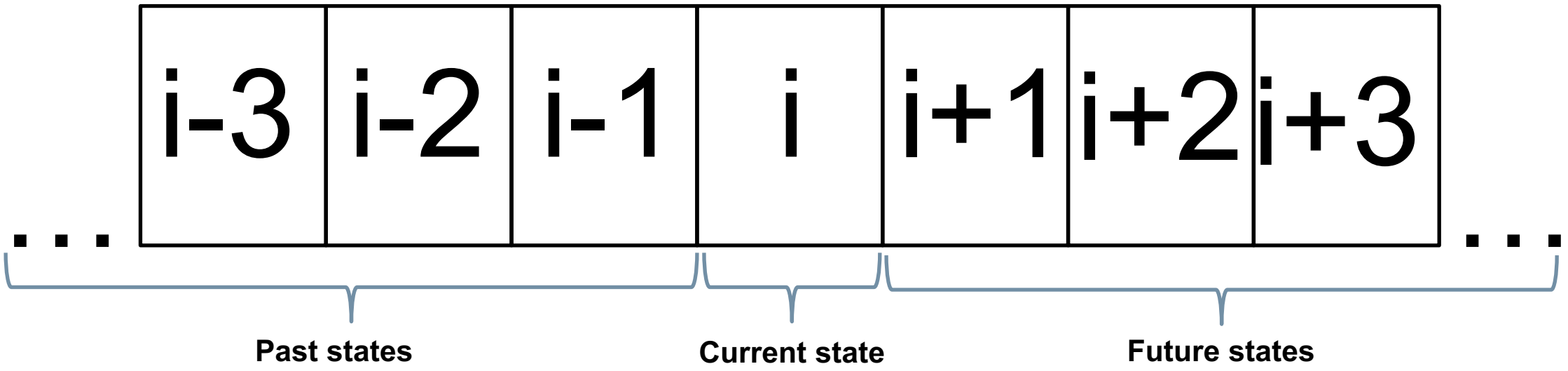
…WE CAN DO BETTER!

https://github.com/AlloyTools/org.alloytools.alloy/releases

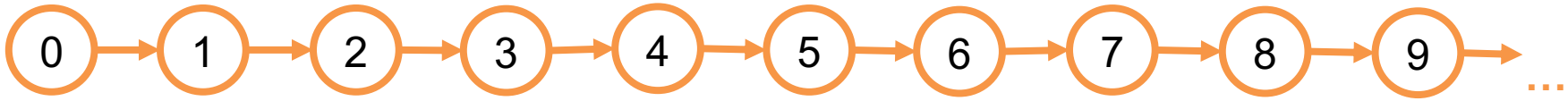
Alloy 6: there is an **implicit**, built-in notion of **(discrete) time**

1. Linear temporal logic
2. Mutable signatures and fields
3. Temporal operators
4. Time horizon
5. New visualizer

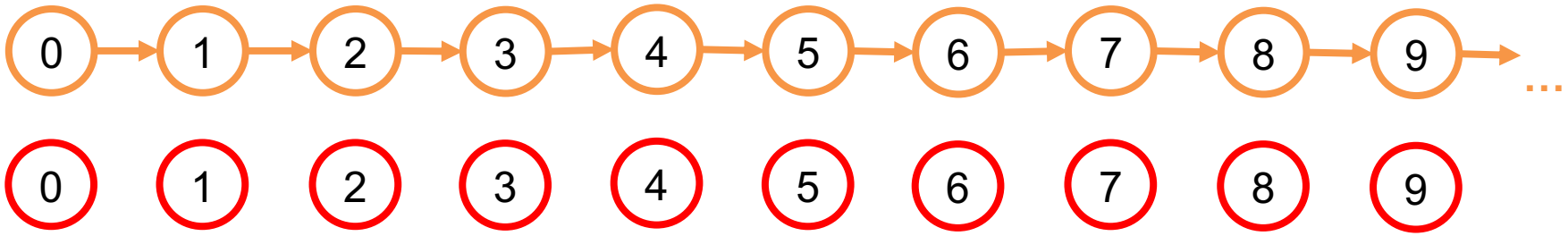
LINEAR TEMPORAL LOGIC (LTL): *«an infinite sequence of states where each point in time has a unique successor, based on a linear-time perspective»*



Trace

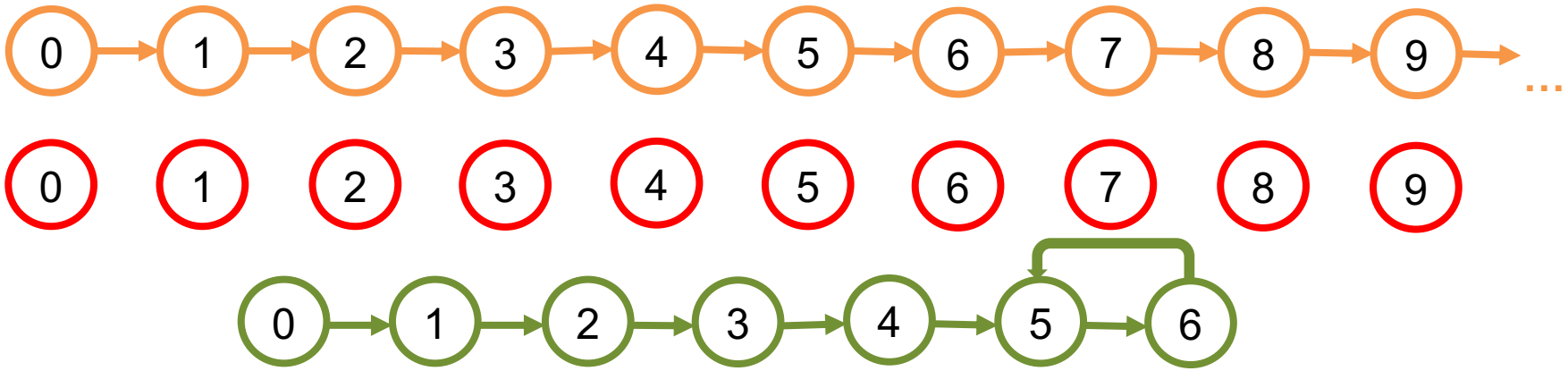


Instance = **TRACE**: infinite sequence of states



Instance = **TRACE**: infinite sequence of states

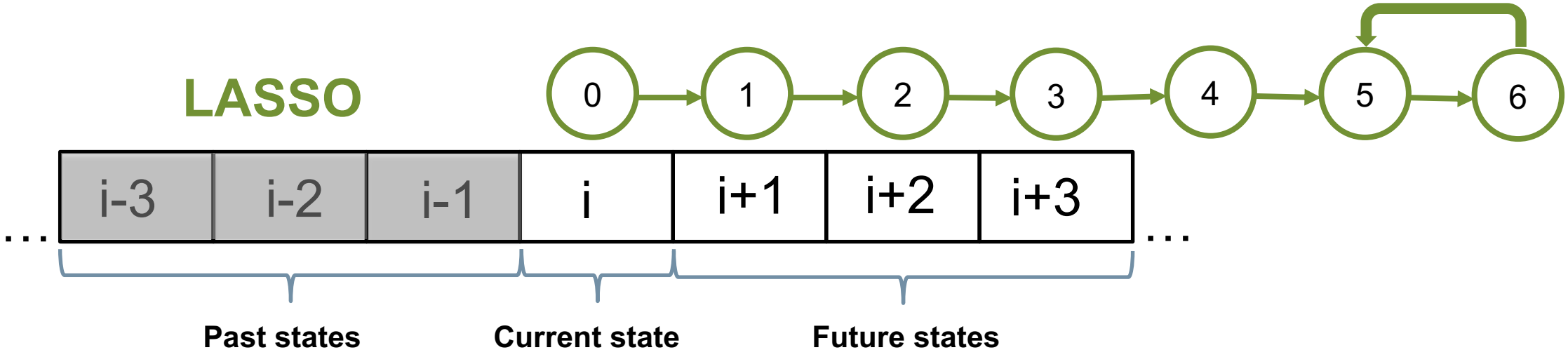
STATE: a valuation for signatures and fields

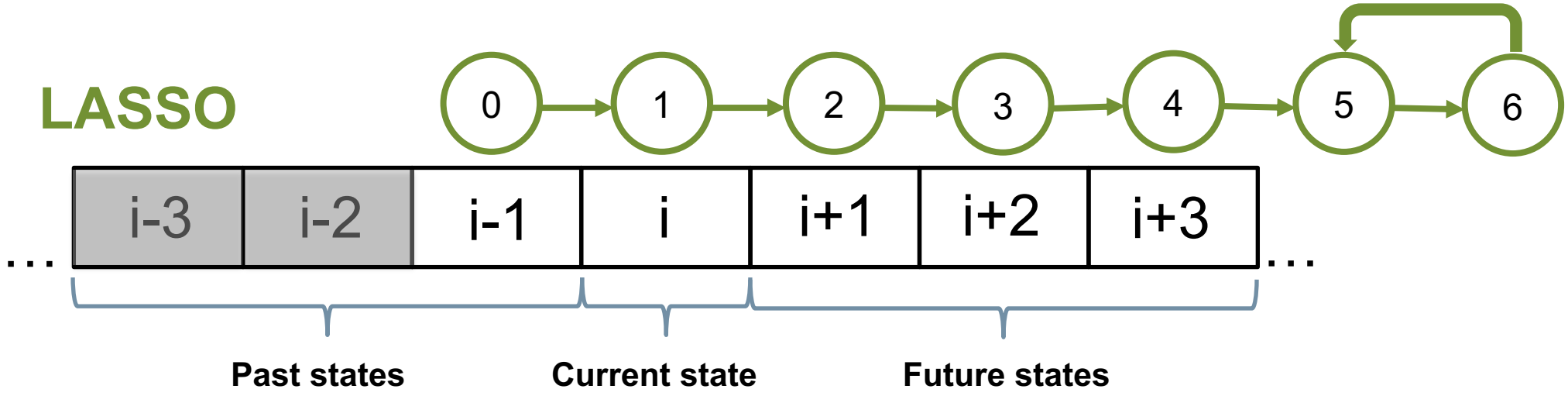


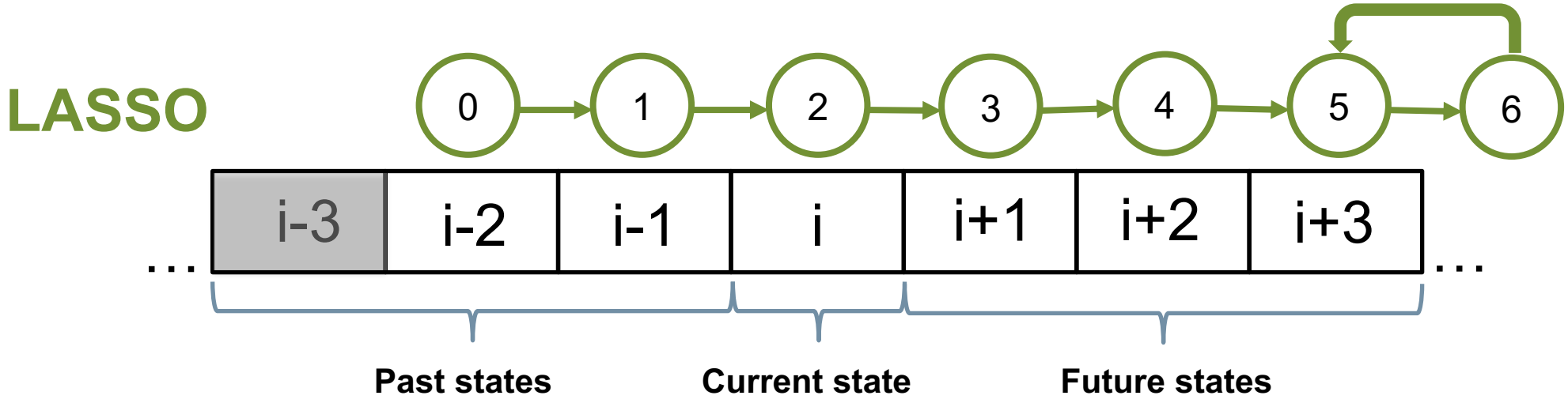
Instance = **TRACE**: infinite sequence of states

STATE: a valuation for signatures and fields

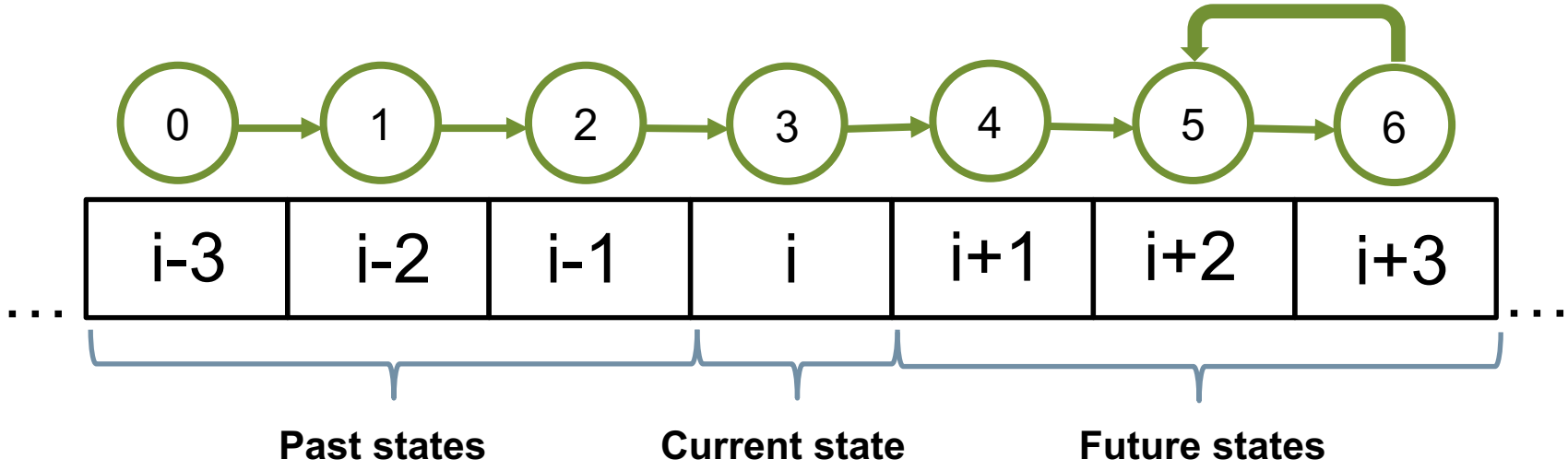
LASSO: a sequence of a finite number of states that loops back to a former state


LASSO
0
1
2
3
4
5
6
i-3
i-2
i-1
i
i+1
i+2
i+3
Past states
Current state
Future states

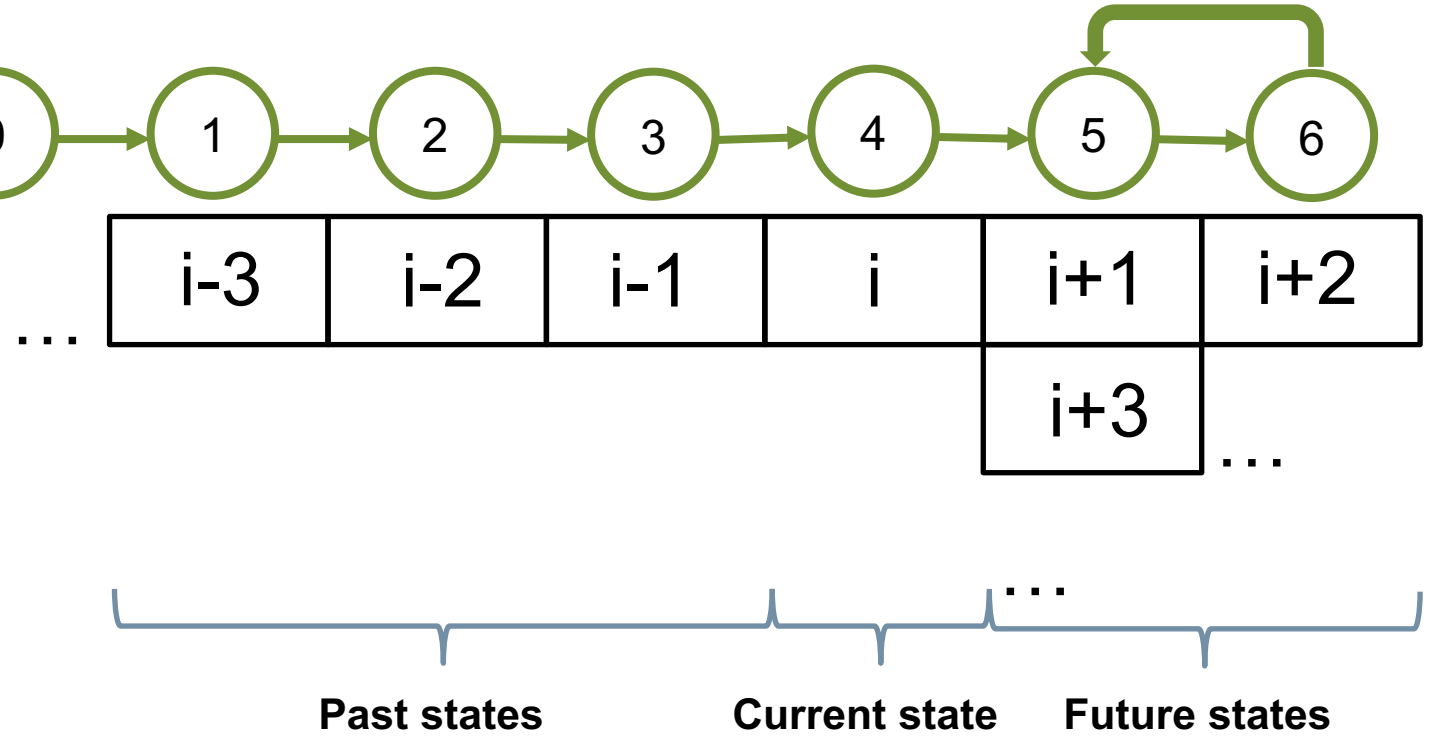

LASSO
0
1
2
3
4
5
6
i-3
i-2
i-1
i
i+1
i+2
i+3
Past states
Current state
Future states


LASSO
0
1
2
3
4
5
6
…
i-3
i-2
i-1
i
i+1
i+2
i+3
…
Past states
Current state
Future states

LASSO


0
1
2
3
4
5
6
i-3
i-2
i-1
i
i+1
i+2
i+3
Past states
Current state
Future states

LASSO


0
1
2
3
4
5
6
…
i-3
i-2
i-1
i
i+1
i+2
i+3
…
…
Past states
Current state
Future states

Alloy 6: an **implicit**, built-in notion of **(discrete) time**

1. Linear temporal logic
2. Mutable signatures and fields
3. Temporal operators
4. Time horizon
5. New visualizer

VAR

- A signature or field proceeded by **var** is said to be **mutable**
- A signature or field **not** proceeded by **var** is said to be **static** and assumed to be **constant** over time

```
enum Liveness {Alive, Dead, Unborn}

abstract sig Person {
    father: lone Man
    mother: lone Woman
    var liveness: Liveness
}

sig Man extends Person {
    var wife: lone Woman
}

sig Woman extends Person {
    var husband: lone Man
}
```

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TEMPORAL OPERATORS

Future and Past operators

FUTURE	PAST
ALWAYS	HISTORICALLY
EVENTUALLY	ONCE
AFTER	BEFORE
UNTIL	SINCE
RELEASES	TRIGGERERD
;	(NO DUAL)

…FOR MORE INFO: https://www.youtube.com/watch?v=GncsAmy29l0

Flipped Classroom

Video on Temporal Operators

Link Video

10 min.

Quiz 1

Dynamic modeling in Alloy 5

https://forms.office.com/e/9bjmhZTQ0j

10 min.

1. What is a dynamic model?
   - ❑ A model that represents something static.
   - ❑ A model that represents something changing over time.
   - ❑ A model that has a first-class notion of time.
2. How is time emulated in Alloy 5?
   - ❑ By using utility macros.
   - ❑ By placing an ordering on some signature.
   - ❑ By encoding it in the signature fields.
3. What is a trace in Alloy 5?
   - ❑ A fact that describes how the system will evolve.
   - ❑ A module that helps to model time.
   - ❑ A predicate that relates each state to the next state in the sequence.
4. What is the purpose of a time signature?
   - ❑ To represent complex specifications with multiple changing entities or properties.
   - ❑ To represent simple boolean properties that change over time.
   - ❑ To encode arbitrary properties with multirelations.

Quiz 2

LTL and Mutable Signatures and Fields

https://forms.office.com/e/G3MzQugLb5

10 min.

1. What does the 'var' keyword do in Alloy 6?
   - ❑ Specifies that a signature or field is constant over time
   - ❑ Specifies that a signature or field is mutable
   - ❑ Specifies that a signature or field is a trace
   - ❑ Specifies that a signature or field is a lasso trace
2. What is a static signature or field in Alloy 6?
   - ❑ A signature or field that is constant over time
   - ❑ A signature or field that is a trace
   - ❑ A signature or field that is a lasso trace
   - ❑ A signature or field that is mutable
3. What is linear-time temporal logic used for in Alloy 6?
   - ❑ Reasoning about future and past states along a trace
   - ❑ Reasoning about constant values
   - ❑ Reasoning about mutable values
   - ❑ Reasoning about lasso traces

Quiz 3

Temporal Operators

https://forms.office.com/e/d5Himvahqs

10 min.

1. What is the condition for the expression "F until G" to be true in state i?
   - ❑ G is true in some state j ≥ i and F is true in every state k such that i ≤ k < j
   - ❑ G is true in every state ≥ i up to and including a state k in which F is true
   - ❑ F is true in state i and G is true in state i + 1
2. What is the condition for the expression "F ; G" to be true in state i?
   - ❑ G is true in some state j ≥ i and F is true in every state k such that i ≤ k < j
   - ❑ G is true in every state ≥ i up to and including a state k in which F is true
   - ❑ F is true in state i and G is true in state i + 1
3. What is the condition for the expression "always F" to be true in state i?
   - ❑ F is true in some state ≥ i
   - ❑ F is true in every state ≥ i
   - ❑ F is true in state i + 1
4. What is the condition for the expression "eventually F" to be true in state i?
   - ❑ F is true in some state ≥ i
   - ❑ F is true in every state ≥ i
   - ❑ F is true in state i + 1

5. What is the condition for the expression "after F" to be true in state i?
   - ❑ F is true in some state ≤ i
   - ❑ F is true in every state ≤ i
   - ❑ F is true in state i + 1
6. What is the condition for the expression "before F" to be true in state i?
   - ❑ F is true in some state ≤ i
   - ❑ F is true in every state ≤ i
   - ❑ F is true in state i – 1
7. What is the condition for the expression "historically F" to be true in state i?
   - ❑ F is true in some state ≥ i
   - ❑ F is true in every state ≤ i
   - ❑ F is true in state i + 1
8. What is the condition for the expression "once F" to be true in state i?
   - ❑ F is true in some state ≤ i
   - ❑ F is true in every state ≤ i
   - ❑ F is true in state i + 1

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TIME HORIZON
Number of steps

TIME HORIZON: the possible number of transitions of lasso traces to explore

default	#steps = 10	`for 10 steps`
N	1 <= #steps <= N	`for N steps`
M .. N	M <= #steps <= N	`for M .. N steps`
1..	1 <= #steps	`for 1 .. steps`

TIME HORIZON
Model-checking

TIME HORIZON: the possible number of transitions of lasso traces to explore