Model-Based Testing

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Lecture 2
Specification and Black Box Testing

Gerardo Schneider
Dept. of Computer Science and Engineering
Chalmers | University of Gothenburg

(Some slides based on material by Magnus Björk)

Student Representatives

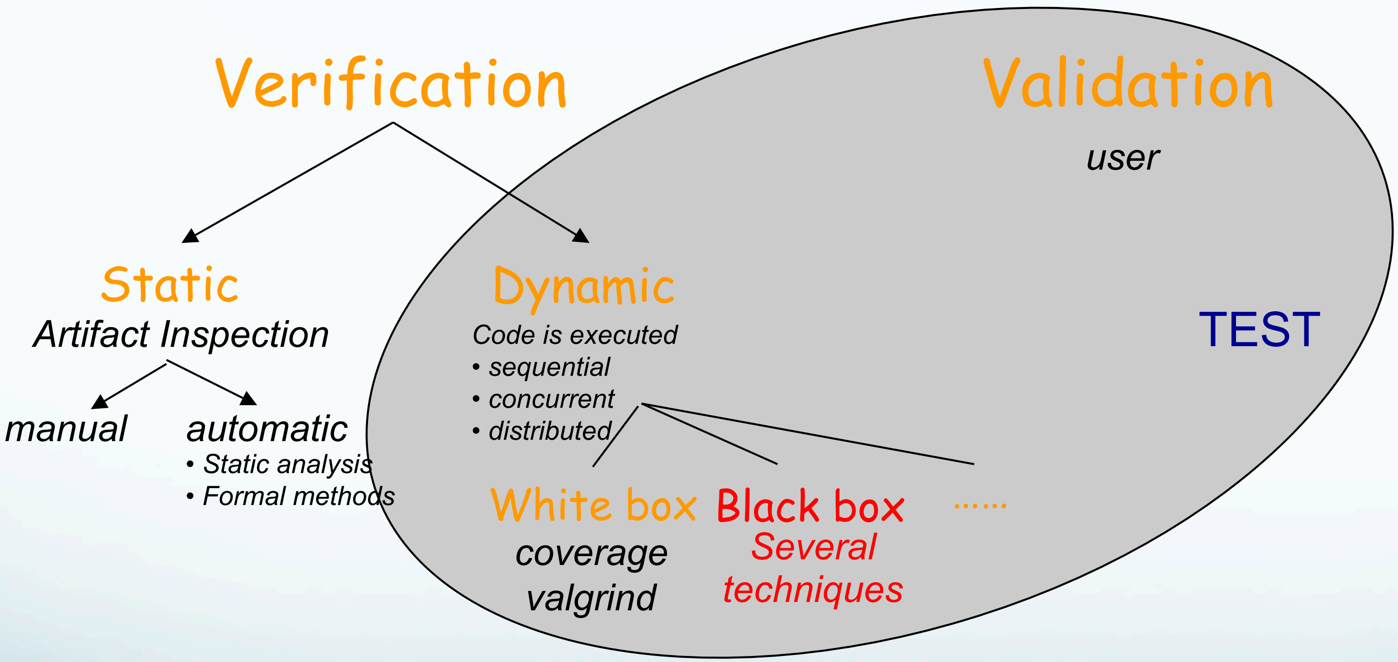
Chalmers

1. ÍVAR H. JÓHANNESSON (MPSOF) varh@student.chalmers.se
2. RADHA THIAYAGARAJAN (MPSOF) radha@student.chalmers.se
3. YASAMAN VAZIRI (MPNET) vaziri@student.chalmers.se
4. MAGNUS ÅGREN (MPALG) magagr@student.chalmers.se

GU

- Henrik Larsson (SE) henke@henkelarsson.se

Terminology



Test cases

- Clear description of tests to be performed
  - Possible for a colleague or a computer to perform

- Manual, scripted or automatic:
  - Manual:
    - Clear text description for humans
    - Typically used for system properties
  - Scripted:
    - Executable description for computers
    - Typically used for lower level properties (unit tests, etc)
    - E.g. in xUnit, DejaGnu, bash or perl
    - Must still be readable for developers!
      - Serves a documentation purpose
  - Automatic:
    - Automatically generated and executed by computer
    - Based on formal specification

Test case 'elements'

- **Fundamental** components
  - Action: what to do in the test
  - Expected outcome: how the system should respond
    - **Good** expected outcomes are specific
      - "The function call returns 3"
      - "'Hello World!' is printed on the screen"
    - **Bad** expected outcomes:
      - "The expected number is returned"
- **Optional** components:
  - Id/name
  - Description/purpose
  - Reference to requirement/ part of specification
  - Preconditions
  - Initialization
  - More: see IEEE 829

- **Typically...**
  - Id/name
  - Description/purpose
  - Precondition
  - Initialization
  - Action
  - Expected outcome

Example: Test case for CD player

Id: CDP-Vol-1

Purpose: checking volume control

Precondition: Music is playing and heard in speakers

- **Action a**: Turn volume control, try both directions
  - **Expected outcome**: Turning volume control clockwise increases volume of music, counterclockwise decreases volume
- **Action b**: Turn volume control counterclockwise as far as possible
  - **Expected outcome**: Music playback completely silent at stop
- **Action c**: Turn volume control slightly clockwise
  - **Expected outcome**: Music is audible within 3mm of silent position

Test cases and specifications

- A test case verifies fulfilment of some particular aspect of the specification
- Test cases are usually (initially) derived from the specification
  - Coverage techniques help to direct focus
- A bunch of test cases is **not** a specification

Software specification

- What is the software supposed to do?
- Functional and non-functional properties
  - Functional: Specific behaviour of system
    - If user does X, then system does Y
    - Normally only refers to interface of the component being specified
  - Non-functional
    - Other properties, such as:
      - Efficiency
      - Usability
      - Performance
      - Coding standards
      - Licensing

Different kinds of specifications

Informal specifications:

- Descriptive text

(Semi-) formal specifications:

- UML-diagrams
  - Behavior diagrams (use-case diagrams, state diagrams)
  - Interaction diagrams (sequence diagrams, communication diagrams)

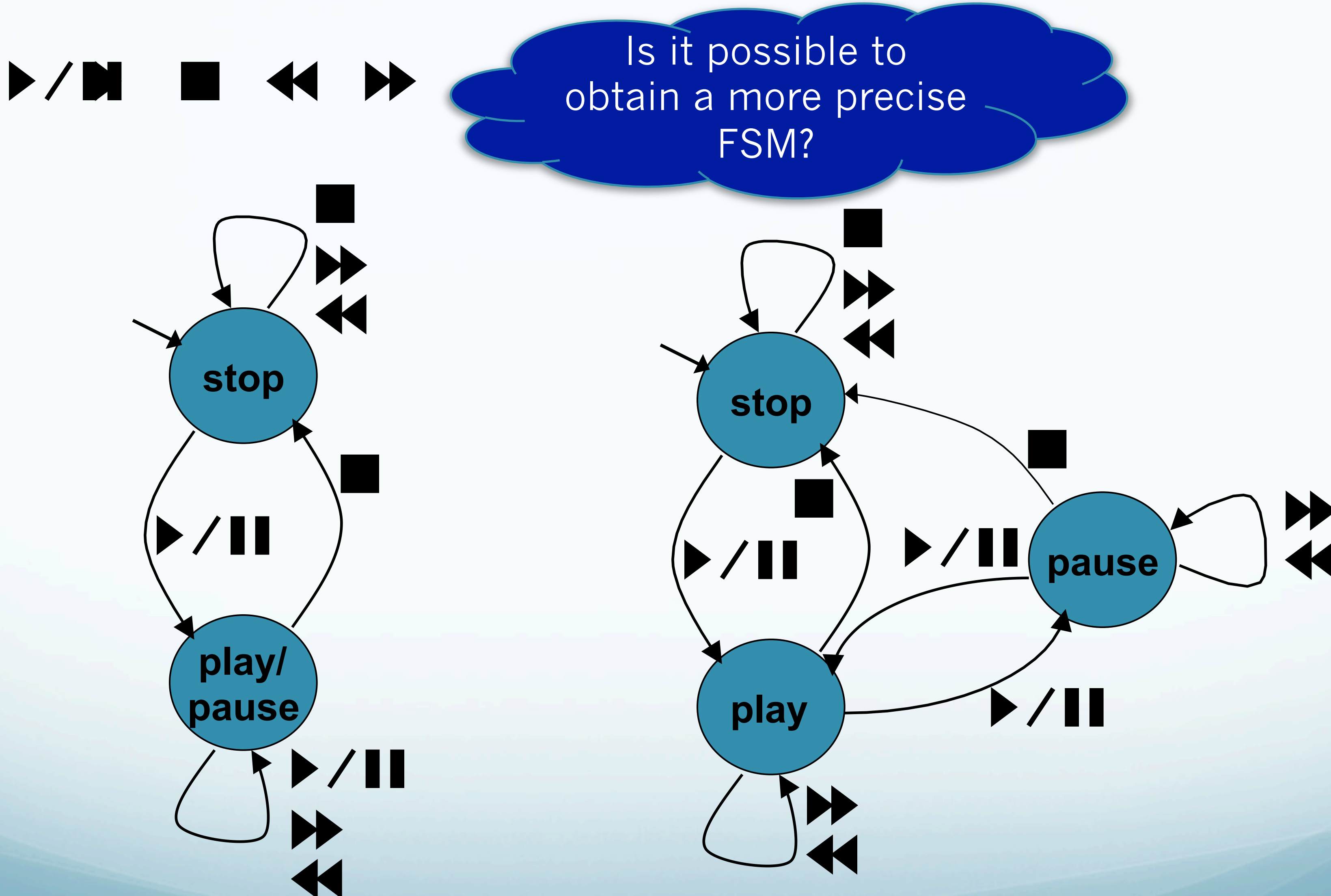
Formal specifications:

- State-machine models
  - Finite-State Machines (FSM)
  - Extended Finite-State Machines (EFSM)
- Algebraic specifications
  - Equations relating functions to each other
- Temporal logic

Finite State Machines (FSM)

- Powerful description mechanism
- Variants of FSM are used in various places (some UML diagrams, formal specification languages, …)
- Consists of
  - A finite number of states
  - Transitions between the states
  - (Very often we also use labels on states/transitions)

Example: FSM of a CD-player



CD-player FSMs

- The first version is a "***model***" of the second
  - Alternative (better) terminology: **abstraction**
  - Warning! Depends who you ask and how "precise" you want to be: abstraction and model are not the same!
  - A model is an abstract representation of the reality
    - It provides a simpler view of a property/system
    - In some cases information is lost, in others is not
      - First FSM adequate for "motor running"
      - First FSM **not** adequate for "music is playing"
  - Abstraction is the process of taking away characteristics from something in order to reduce it to a set of essential ones
    - It typically only retains information which is relevant for a particular purpose
    - There is a lost of information
    - Ex: "Odd-Even" is an abstraction of the natural numbers
- Both FSM versions are models of the whole (real) player
  - Do not include e.g. current track and position of laser pickup

Manual test case (example)

Name: CD Play 1

Purpose: Checking basic playback

Preparation: Turn on CD-player with CD in tray

- Action: Press Play/Pause
- Expected outcome: CD starts playing

More manual test cases (example)

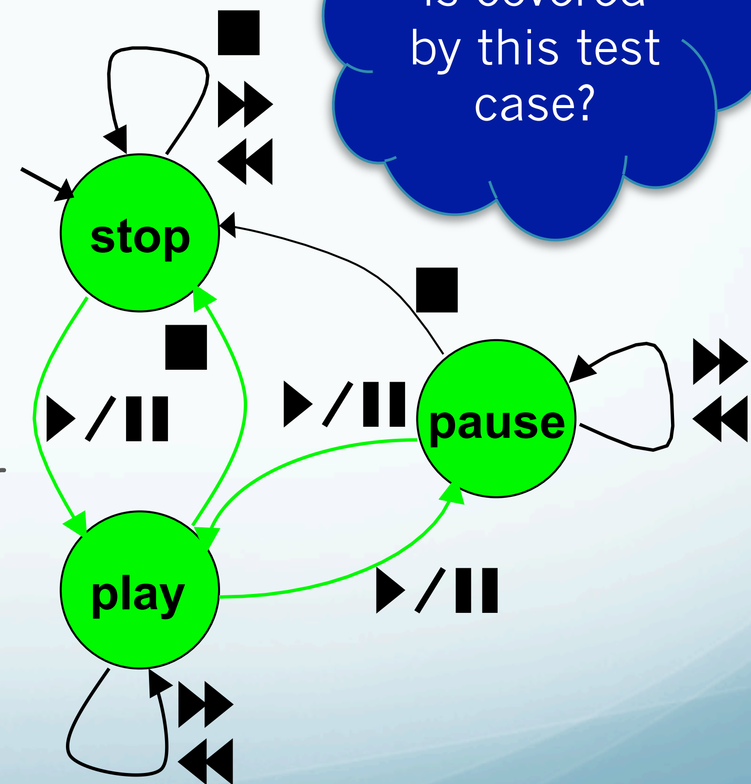
Name: CD Play 2

Purpose: Checking playing, pausing, and stopping

Preparation: Turn on CD-player with CD in tray

- Actions:
  - a: Press Play/Pause
    - Expected outcome: CD starts playing
  - b: Press Play/Pause
    - Expected outcome: CD stops playing
  - c: Press Play/Pause
    - Expected outcome: CD starts playing where it stopped
  - d: Press Stop
    - Expected outcome: CD stops playing
  - e: Press Play/pause
    - Expected outcome: CD starts playing from beginning of first track

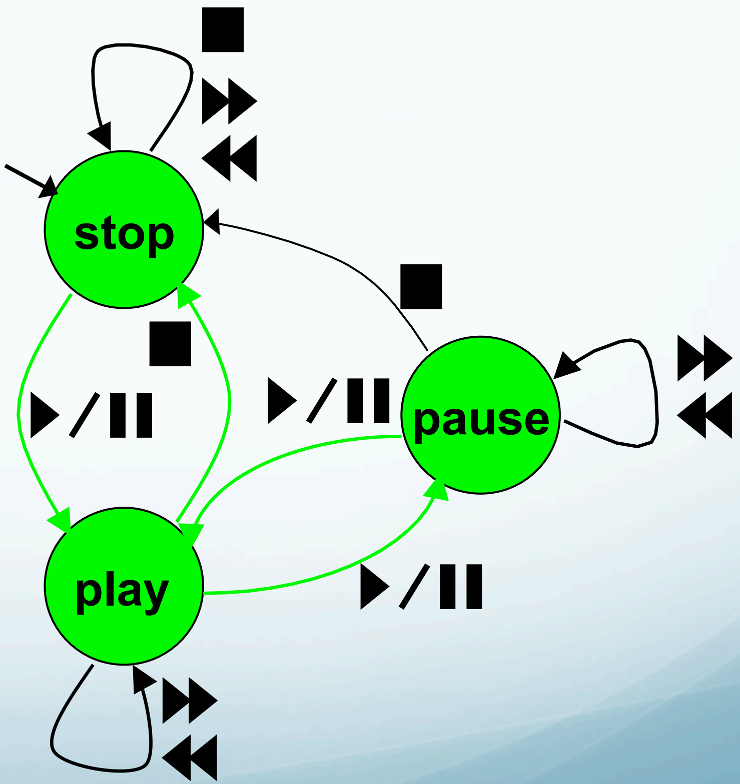
How much is covered by this test case?



More manual test cases (example)

Specification coverage:

- Covered states:
  - 3 of 3
- Covered transitions:
  - 4 of 12
    - Some transitions superpositioned in figure
- Uncovered transitions can give a hint of missing test cases



FSM: To think about…

- About transitions
  - One transition out of each node for each possible event
  - Some transitions missing
    - Cannot happen
    - Error if happens
    - Ignored if happens
  - No labels? Maybe the transition is not needed
  - Deterministic/nondeterministic
    - Deterministic FSM
      - It's in exactly one state at any time
      - Only one transition possible to take
    - Nondeterministic FSM
      - Several states may be active at a time
      - Several transitions may be enabled under same input

Random testing against FSMs

- Representing an FSM (Implementation)
  - Set of states (e.g. enum type, bounded integers)
    - One initial state
  - Set of events
  - Transition function: State -> Event -> State
- Useful functions for verifying against FSM
  - Precondition: State -> Event -> Bool
    - Which events can happen now?
  - Postcondition (expected outcome):
    State -> Event -> SystemState -> Bool
    - Test that the actual system is in a correct state after the transition
    - Looks at the actual system to test
  - Generate events randomly
    - Make sure they respect precondition
- You can implement this in your favourite test framework
- …or get QuickCheck, which does it automatically

Model-based verification

- Writing test cases can be a very tedious task
- State transition systems can be used to automate test case generation (later in this course)
  - Model-based testing
- Advanced tools that automatically check whether a system is modelled by a given FSM
  - Model checking

Extended Finite-State Machines

- Finite-State Machines have concrete state spaces
- Extended Finite-State Machines (EFSM)
  - State space represented by structures like integers, lists, tuples, strings, and enumeration types
  - May have infinite state space
- Random testing against EFSM:
  - Just as for FSM

Example EFSM: CD player

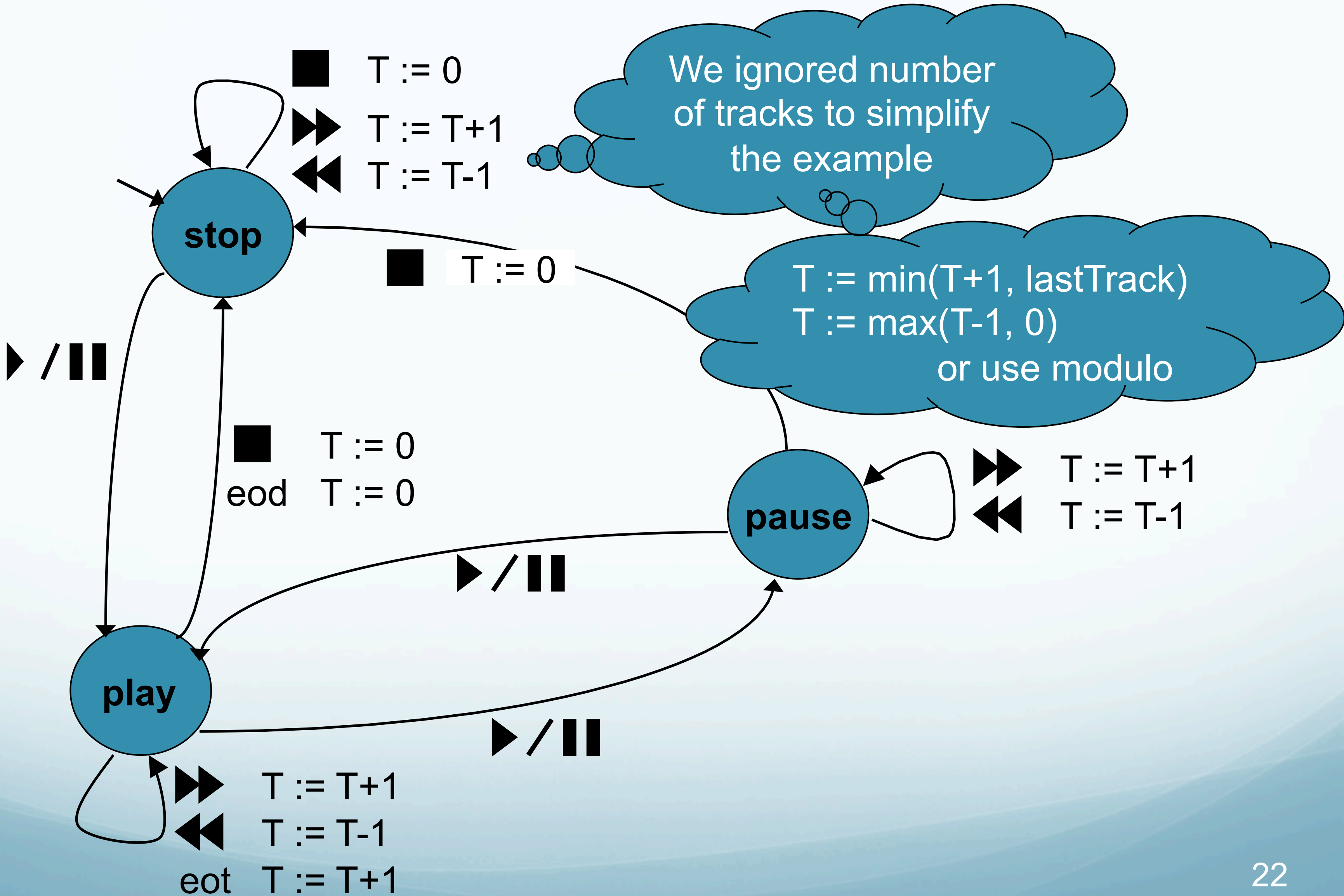
- State representation: **(S,T)**
  - S: Playing state (stopped, playing, paused)
  - T: Track number
- Initial state:
  - (stopped, 1)
- Events:
  - Play/pause pressed
  - Stop pressed
  - Skip forwards pressed
  - Skip backwards pressed
  - End of track reached (eot)
  - End of disc reached (eod)

CD player preconditions

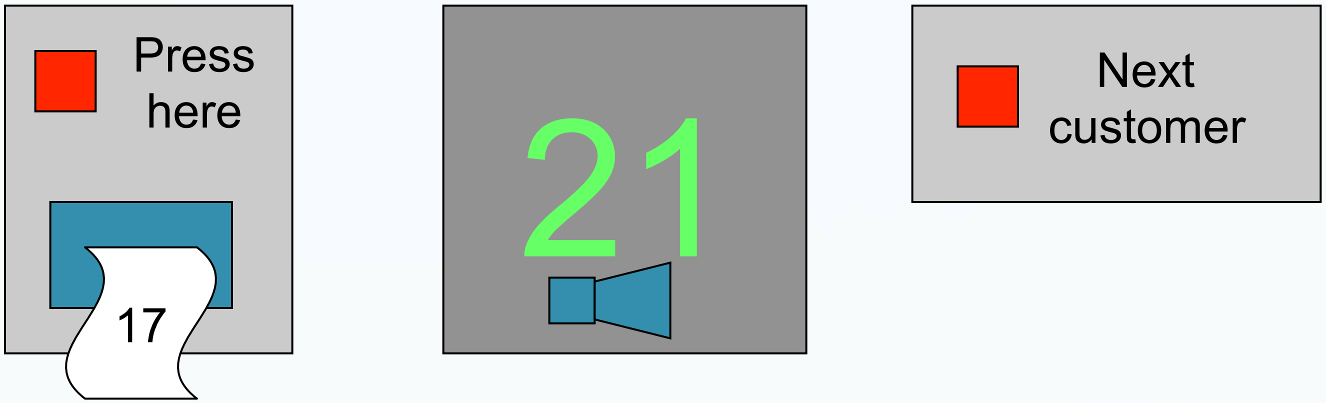
- Almost all events are possible at all times
  - Buttons can be pressed at any time
  - But *eot* and *eod* can only happen during playback
- *precondition((stopped, t), eot)*
  - Is it possible to be in a state where the CD player is not playing and it is "reading" any track *t* and "react" to the end-of-track event?

precondition((stopped, t), eot)	-> false
precondition((paused, t), eot)	-> false
precondition((stopped, t), eod)	-> false
precondition((paused, t), eod)	-> false
precondition((s,t), e) (for any other state s, track t, any other event e may happen?)	-> true

CD Player transitions

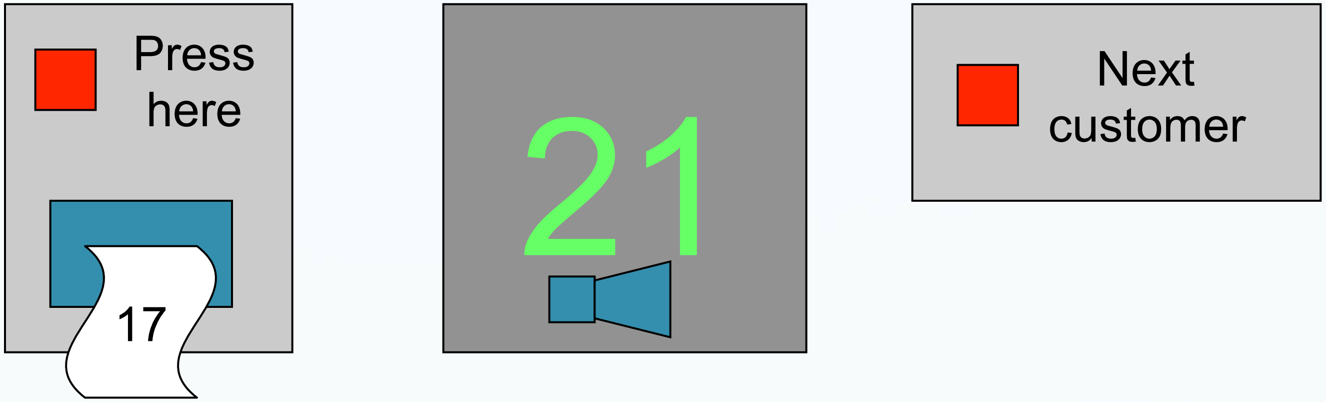


Turn ticket system



- Three units:
  - Customer ticket terminal
    - Button B1 (”press for ticket”)
    - Ticket printer
  - Number display
    - Number display D
    - Speaker S
  - Attendant terminal
    - Button B2 (”next customer”)

Turn ticket system



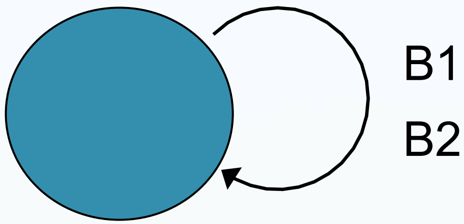
Informal specification

- At entrance, customer presses B1, which causes a ticket to be printed
  - The first ticket has number 1, the number is increased by 1 for successive tickets. Ticket 999 is followed by 0.
- When attendant presses B2
  - If receipts have been printed with higher number than the currently displayed, the display number is increased.
  - If no such receipts have been printed, nothing happens.
- D initially displays the number 0. Display increments adds 1 to the current number, unless the current number is 999 in which case the new number is 0. Each increase is accompanied by a sound from S.

Group exercise

- Come up with a **finite-state machine** that models this system
  - Many different variants exist with different levels of complexity and accuracy
- What are the limitations of your model?
- Come up with an **extended finite state machine** that models the system more accurately
  - Perhaps not based on the FSM, as the CD player was

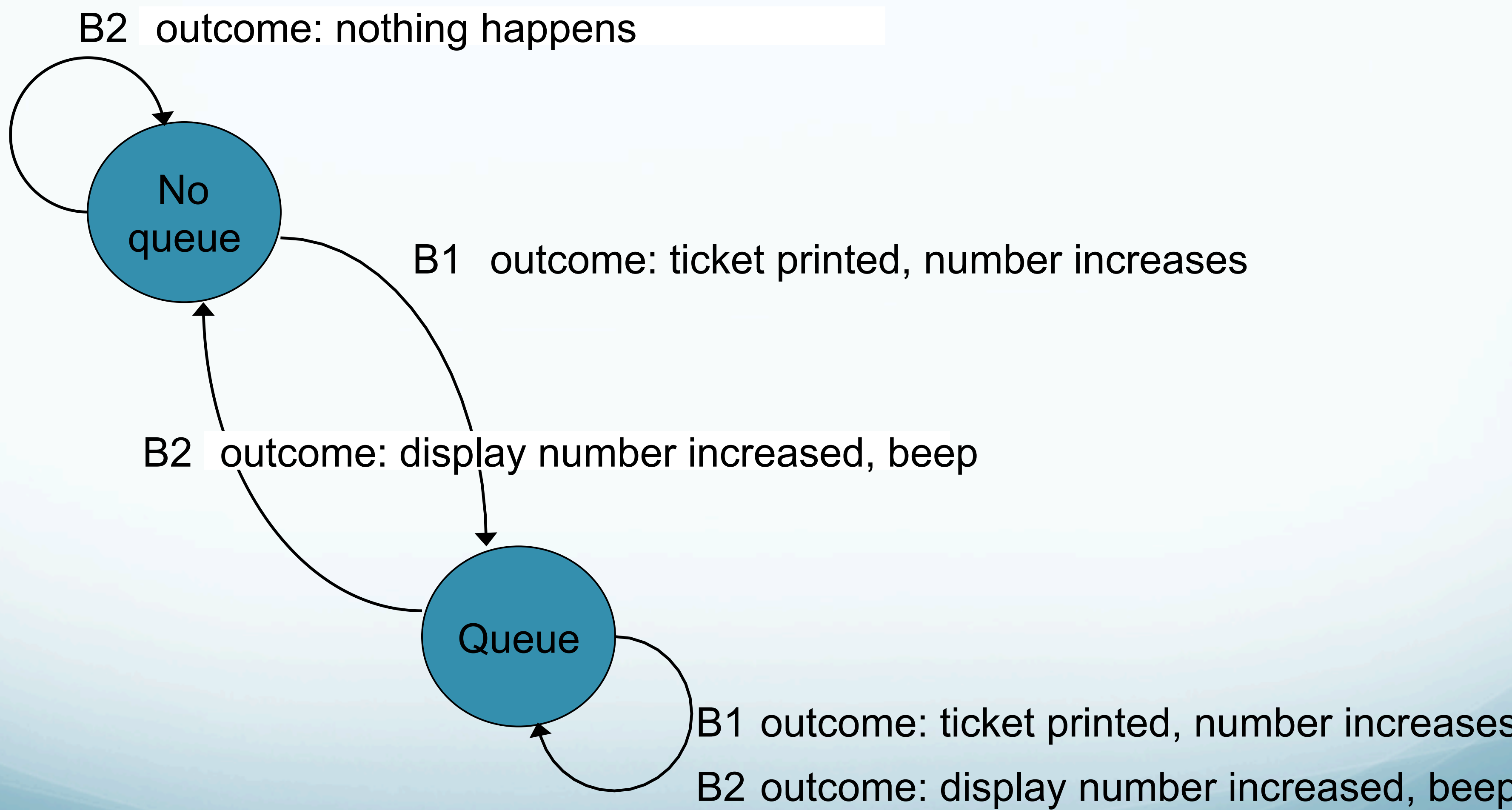
The simplest FSM representation of all



- This FSM models <u>all</u> systems with two events

- Hence, it is useless!

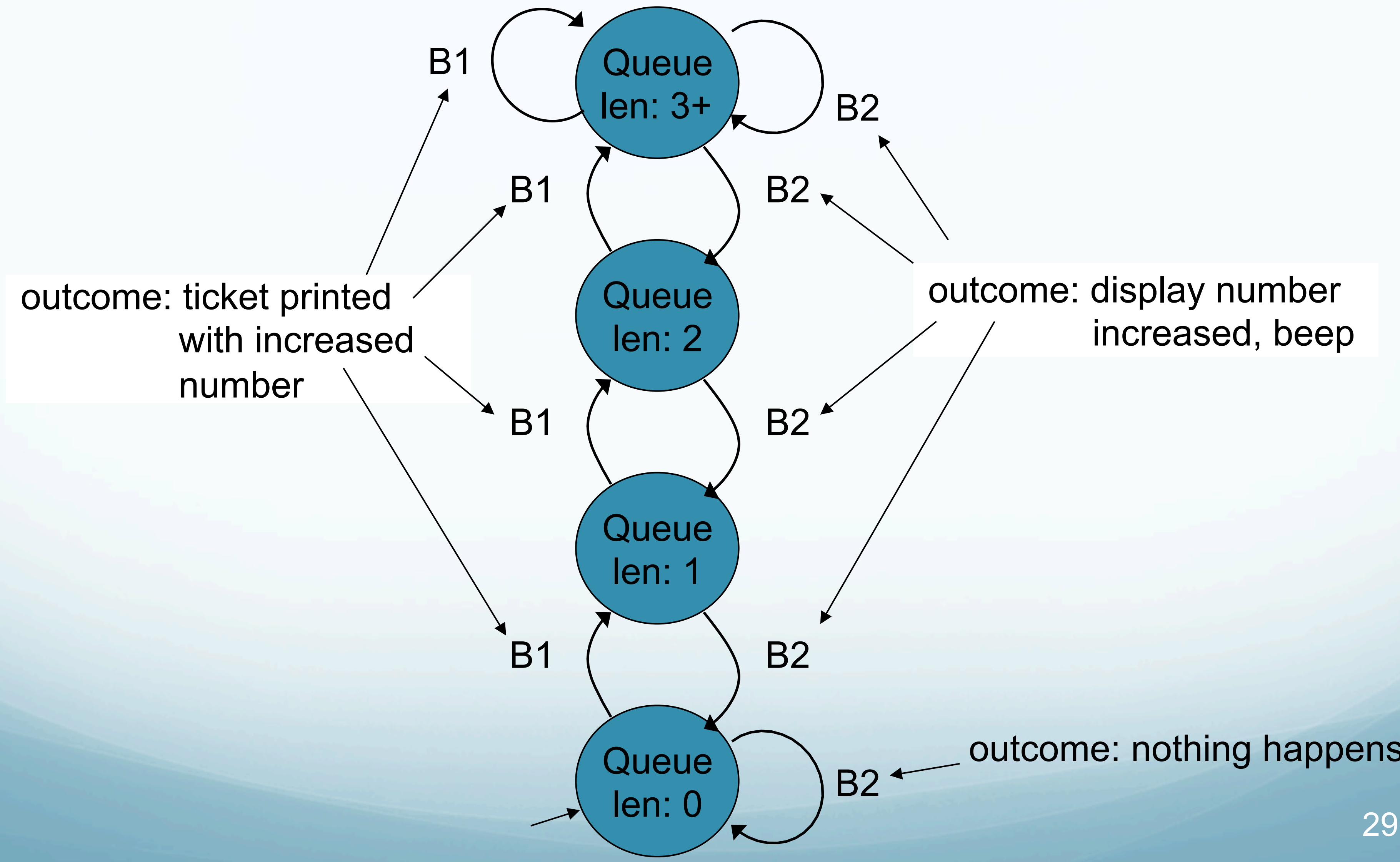
FSM representation
(very simple)



Properties of this FSM

- Simple! (easy to understand, easy to come up with)
- Nondeterministic
  - (Why?)
- Can determine:
  - Correct behaviour of one B2 press after a B1
- Cannot determine:
  - Correct behaviour of multiple B2 presses
  - Exact numbers on tickets and display
- Useful for:
  - Understanding
  - Writing some testcases
  - Automatically prove some properties

FSM representation
(bounded queue)

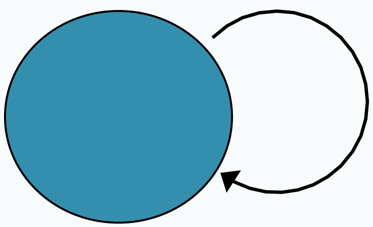


Properties of this FSM

- Still rather simple
- Still nondeterministic (in top state)
- Can determine
  - Correct behaviour as long as not more than 2 people in queue
- Cannot determine
  - Correct behaviour with more than 2 people in queue
  - Exact numbers on tickets and display
- Useful for
  - Understanding
  - Writing more testcases? (probably not more than first)
  - More accurate automated testing

EFSM representation 1

- State:
  - Number of people in queue (n)



```
B1  n := n+1
B2  if n >= 1 then
        n := n-1;
    else
        null;
    fi
```

Expected outcome: ticked printed with increased number

Expected outcome: Display number increased, people in the queue, beep heard

Expected outcome: nothing happens

Properties of this EFSM

- Simple?
- Deterministic!
- Can determine
  - How to act (whether to increase display number)
- Cannot determine
  - Exact numbers on tickets and display
- Useful for
  - Understanding?
  - Even more accurate automated testing

EFSM representation 2

- State:
  - Last printed number (P), currently displayed number (Q)
  - Initial state: P=0, Q=0

We'll say that variables in expected outcome refer to new value

- Next state function:
  - B1: P := P+1 mod 1000
    - Expected outcome: ticket printed with number P
  - B2: if P=Q then

```
      null;   // expected outcome: nothing happens
    else
      Q=Q+1 mod 1000;
          // expected outcome: D displays Q, beep
```

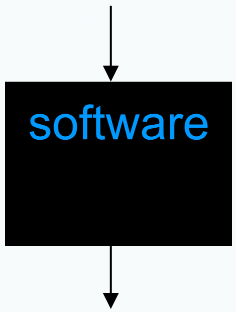
- Precondition function:
  - Anything is possible

Properties of this EFSM

- Harder to understand
  - Encodes the whole "program" in one transition
- Deterministic
- Can determine
  - Full behaviour of system
- Cannot determine
  - Nothing
- Useful for
  - Complete verification of system
  - Starting point of implementation

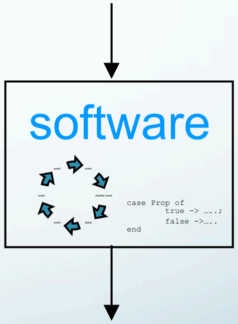
Black box testing

Black box and white box testing



Black box testing: Test tactic in which the test object is addressed as a box one **cannot** open.

A test is performed by sending an **input value** and observing the **output** *without using any knowledge about the test object internals.*



White box testing: Test tactic in which the test object is addressed as a box one **can** open.

A test is performed by sending an **input value** and observing the **output** and internals while explicitly *using knowledge about the test object internals.*

Black Box testing

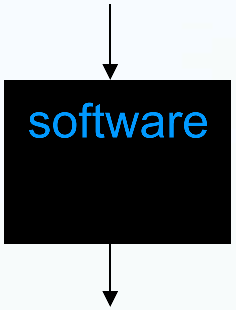
Techniques

- Random Testing
- Equivalence Class Partitioning
- Boundary Value Analysis
- Cause and Effect Graphing
- State Transition Testing
- Error Guessing
- Use case testing
- … …

Techniques tell you how to select the inputs:
How to create a test case

Misleading…

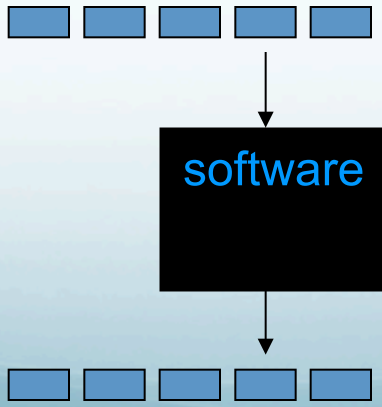
Black box testing is often depicted as:



which might be misleading….

It suggests that *given an input*, the output can be checked against an expected output.

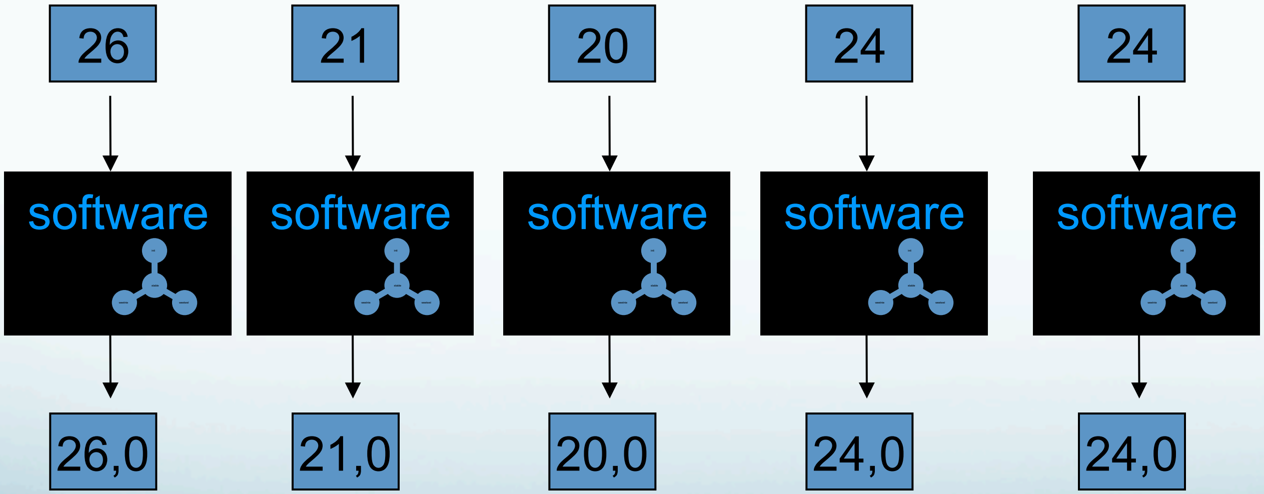
In case the test object has memory, the expected output **depends on the history**!



"Box" has state

Testcase: Start the test object, send 1 value;

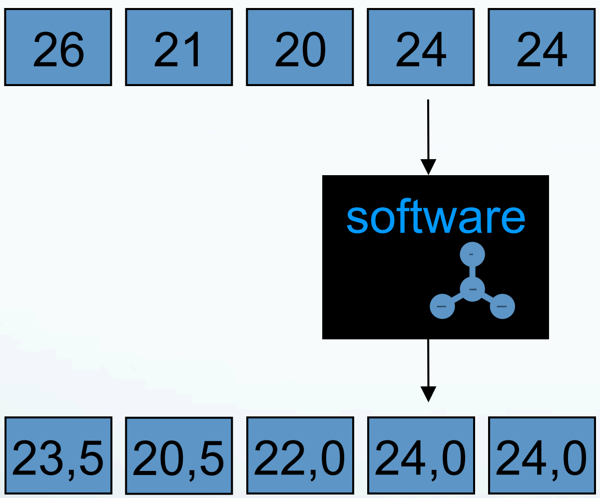
Execute 5 test cases



"Box" has state

Testcase: Start the test object, send 5 values;

Execute 1 test case

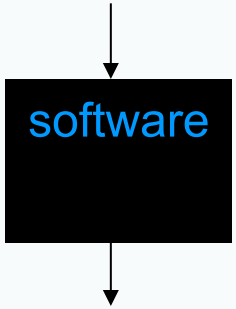


Specification:

Return average temperature over today and yesterday

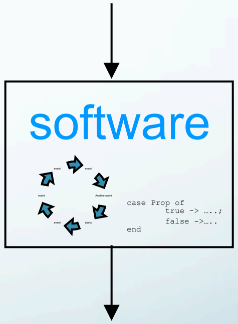
Before execution of a test case, the test object has to be brought into a known state. From there, as many as possible other states should be reached by different test cases.

Black box and white box testing



Black box testing: Test tactic in which the test object is addressed as a box one **cannot** open.

A test is performed by sending ***a sequence of input values*** and observing the **output** without using any knowledge about the test object internals.



White box testing: Test tactic in which the test object is addressed as a box one **can** open.

A test is performed by sending a ***sequence of input values*** and observing the **output** and internals while explicitly using knowledge about the test object internals.

Creating test cases

- Look at the specification, find different cases
  - Enumerate statements in specification, make sure that each aspect is covered by at least one test case
  - Different representations like FSM can help
  - Go through use cases, refine them into test cases
    - Use case: idealized description of interaction with system
    - Test case: detailed description using the system interface
- Equivalence class partitioning
  - In order to reduce number of test cases
  - Find classes of situations where behaviour should be similar
  - FSM specifications really useful

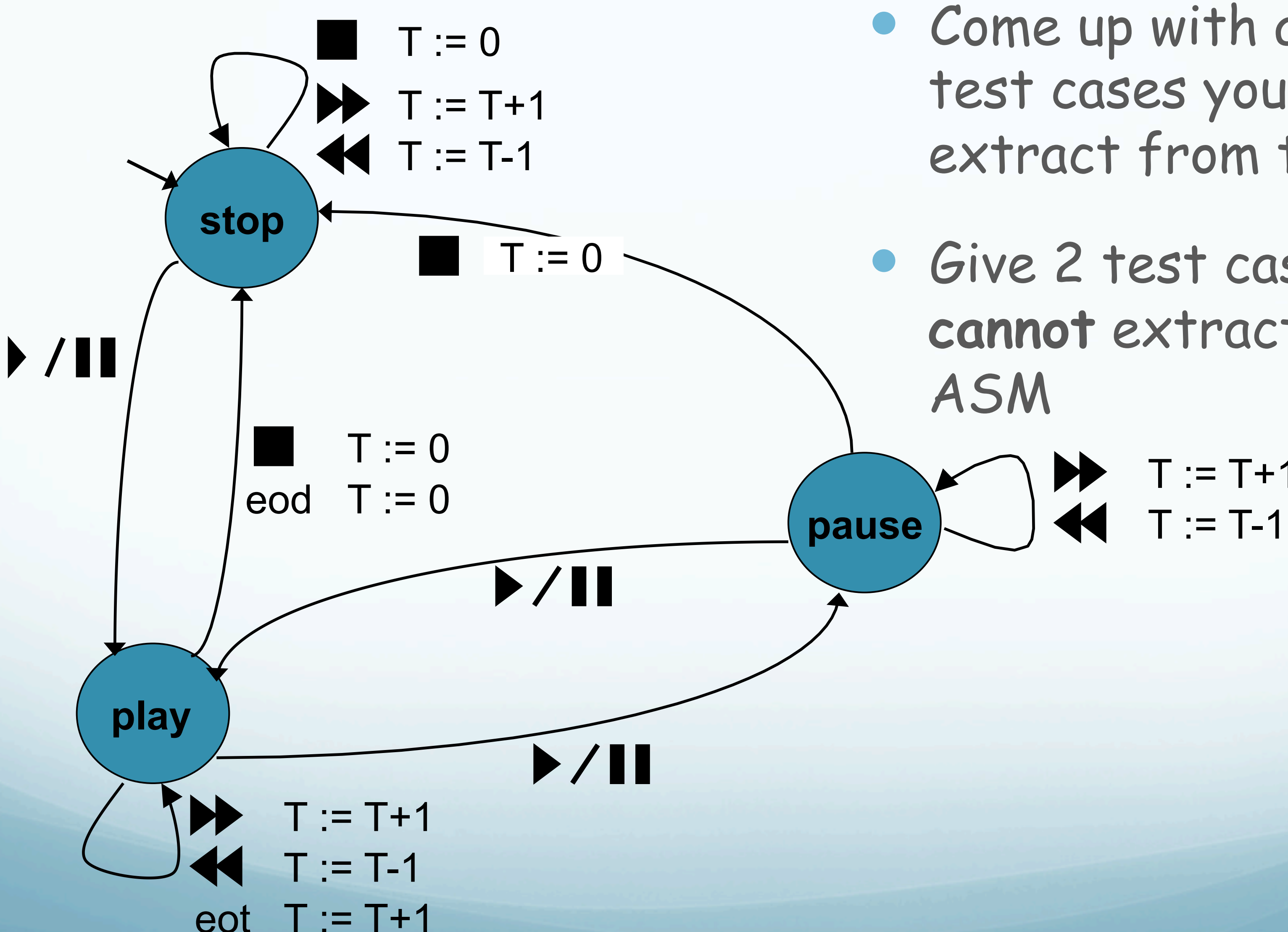
Creating test cases

- Boundary values
  - Malfunctions often occur around boundaries
  - Are there boundaries? Try out values close to limits
    - Maxint? (should system work correctly for maxint?)
    - ATM: What if user wants to withdraw exactly all money from account?
    - CD: Make sure that last track on CD can be played
  - Disadvantage: identifying boundaries may require knowledge about code
    - … but once one knows about the boundaries, the test case can be written without reference to internals
- Error guessing
  - Similar to boundary values: are there values that seem especially dangerous?
    - How about if the century actually ends, so year = 00 ?

Creating test cases

- Random testing
  - Write general test cases
    - Precondition: Account contains m SEK, n <= m
    - Action: User withdraws n SEK from account
    - Expected outcome: New balance is m-n SEK.
  - Generate random sequences of test cases
  - …but try to create sequences that make sense (not much worth if 99.9% of your tests end up in expected failures)
- Code coverage analysis (next lecture)

Group exercise



- Come up with at least 2 test cases you can extract from the EFSM
- Give 2 test cases you **cannot** extract from the ASM

Group exercise

- Examples of test cases you **can** get from the EFSM
  - When the CD player is playing, after pressing ”stop” the player stops
  - When the CD player reaches an ”eot” it changes track
  - When pressing ”pause” and then ”play” (without pressing anything else in between), the track doesn’t change

- Examples of test cases you **cannot** get from the EFSM
  - Cannot test what happens when pressing ”pause/play” and ”stop” at the same time
  - While in ”pause” we cannot test what happens when we press the ”forward” button till the ”eod”

Software Problems in Automobiles A real case

- The AC of the car didn't work when certain sequence of actions were done
  - Put the key, take it, and put it again with certain time before turning on the engine
- Where was the problem?
- Who was responsible (that part of the software was outsourced)

How to identify the problem and find a solution?

- **Specification** was semi-formal (rather informal) some parts written as a FSM
- There was a transition with condition "A, B". Any problem?
  - Engineers from car company: "," was an OR but subcontractors interpreted as an AND

Software Problems in Automobiles
A real case

- The AC of the car didn't work when certain sequence of actions were done
  - Put the key, take it, and put it again with certain time before turning on the engine
- W
- W
  so

Specifications are important!!
Precise, unambiguous, clear - Formal!

How to ider the problem and find a solution?

- **Specification** was semi-formal (rather inf as a FSM
- There was a transition with condition "A,
  - Engineers from car company "," was an OR bu ors interpreted as an AND

Btw, not found with testing but by using Formal Methods

Next lecture

White Box Testing and Coverage