

Model-Based Testing

(DIT848 / DAT261)

Spring 2017

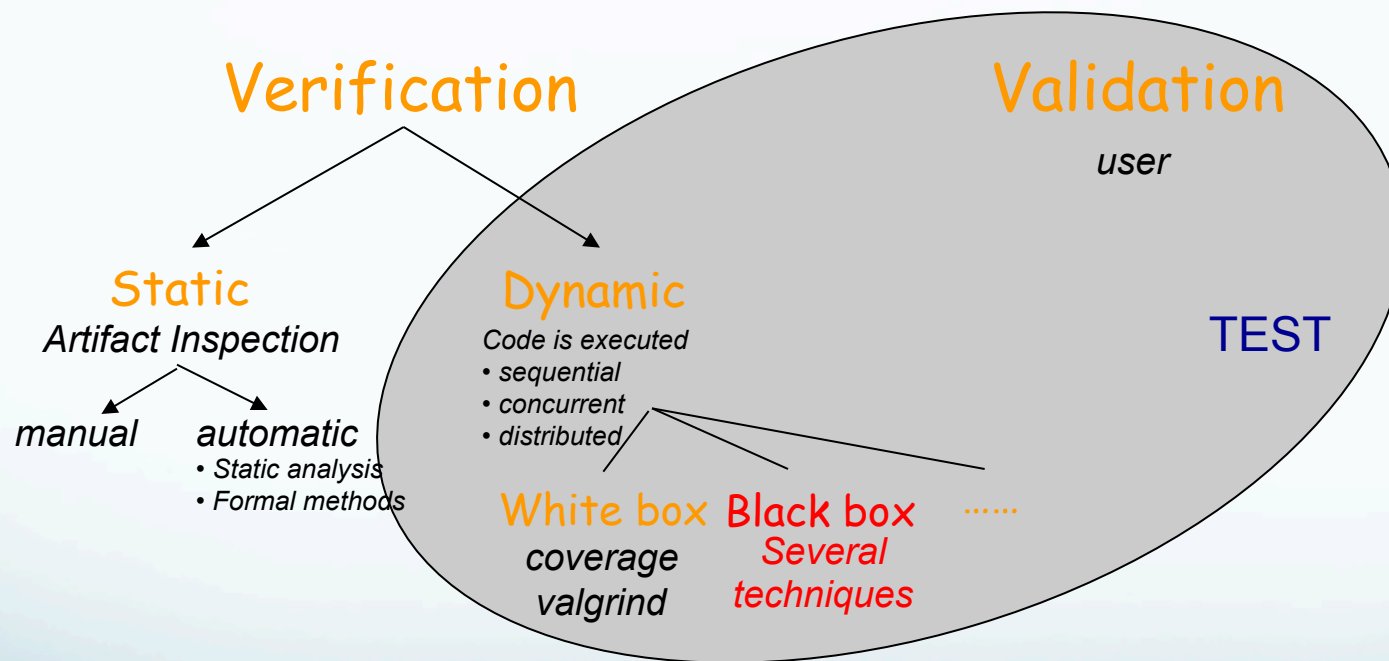
Lecture 2 Specification and Black Box Testing

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(Some slides based on material by Magnus Björk)

Terminology



Test cases

- A **test case** consists of a clear description of tests to be performed
 - Possible for a colleague or a computer to perform (even a monkey)
- 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**

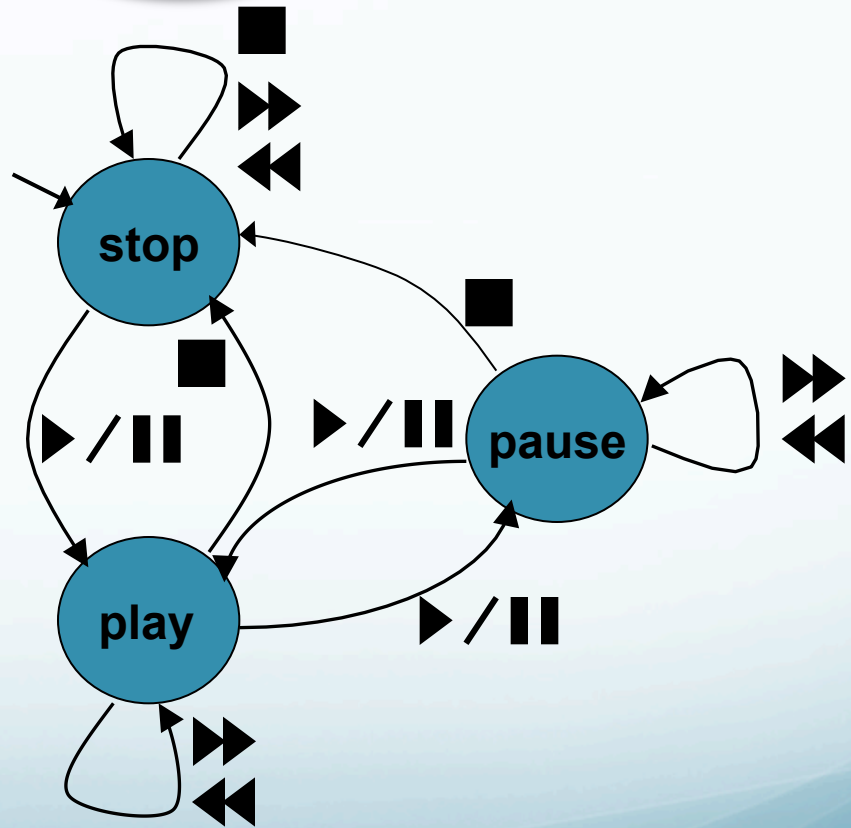
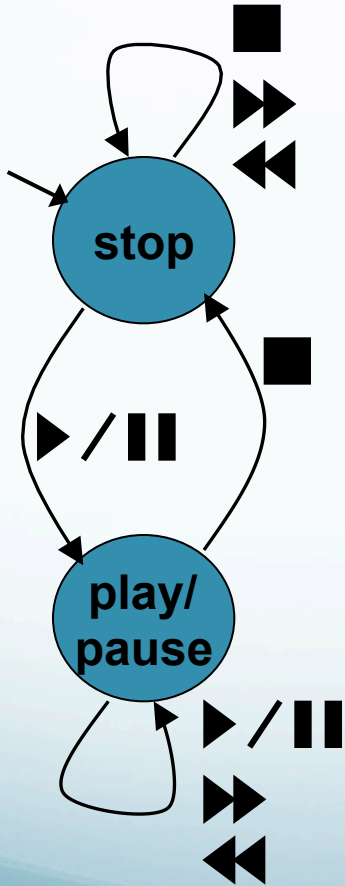
Finite State Machines (FSM)

- Powerful description mechanism
- Variants of FSMs are widely used (some UML diagrams, formal specification languages, EFSMs ...)
- 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

▶ / ▶▶ ■ ◀◀ ▶▶

Is it possible to obtain a more precise FSM?



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 loss 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

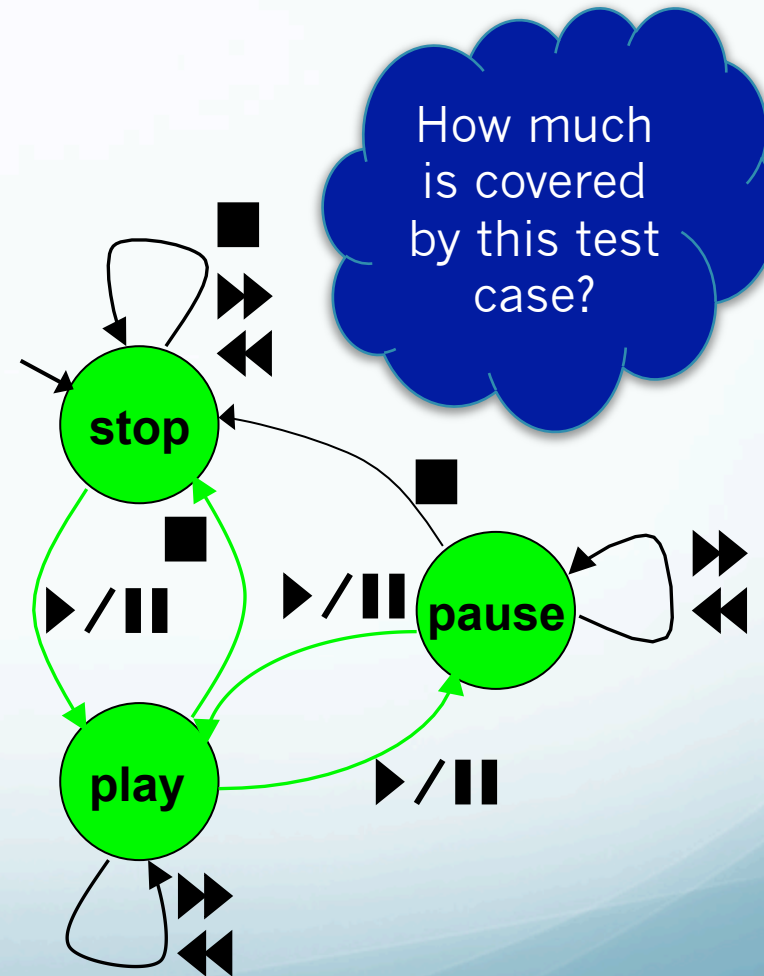
More manual test cases (example)

Name: CD Play 2

Purpose: Checking playing, pausing, and stopping

Preparation: Turn on CD-player with CD in tray

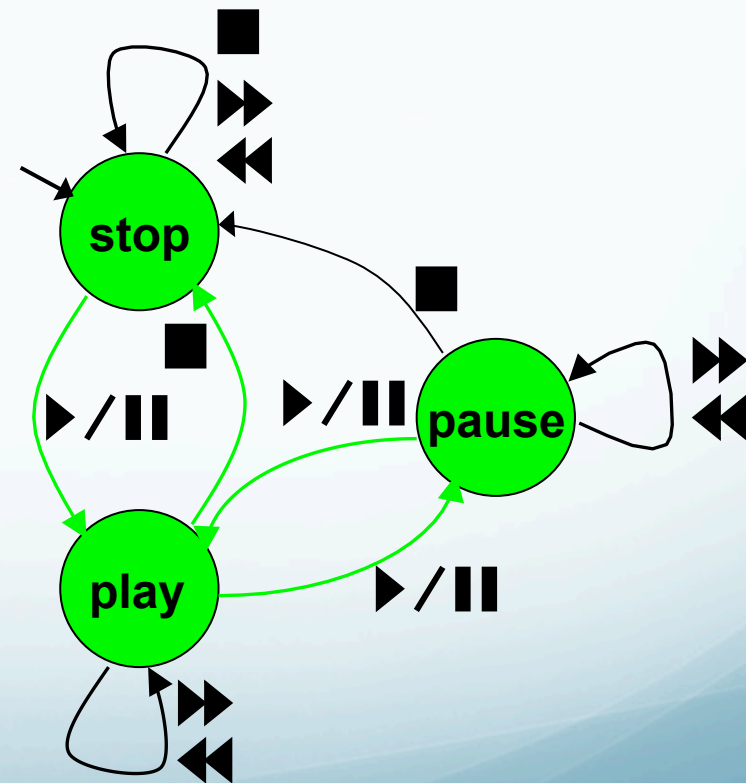
- Actions:
 - a: Press Play/Pause
 - Expected outcome: CD starts playing
 - b: Press Play/Pause
 - Expected outcome: CD stops playing
 - c: Press Play/Pause
 - Expected outcome: CD starts playing where it stopped
 - d: Press Stop
 - Expected outcome: CD stops playing
 - e: Press Play/pause
 - Expected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



More manual test cases (example)

Specification coverage:

- Covered states:
 - 3 of 3
- Covered transitions:
 - 4 of 12 (green ones)
 - Some transitions superpositioned in the 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
 - Each successor state uniquely determined by a given action
 - Only one transition possible to take
 - **Nondeterministic** FSM
 - Several states could be reached after a given action
 - 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: $\text{State} \rightarrow \text{Event} \rightarrow \text{State}$
- Useful functions for verifying against FSM
 - Precondition: $\text{State} \rightarrow \text{Event} \rightarrow \text{Bool}$
 - Which events can happen now?
 - Postcondition (expected outcome):
 $\text{State} \rightarrow \text{Event} \rightarrow \text{SystemState} \rightarrow \text{Bool}$
 - 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 (*eot*)?

precondition((stopped, t), eot) -> false

precondition((paused, t), eot) -> false

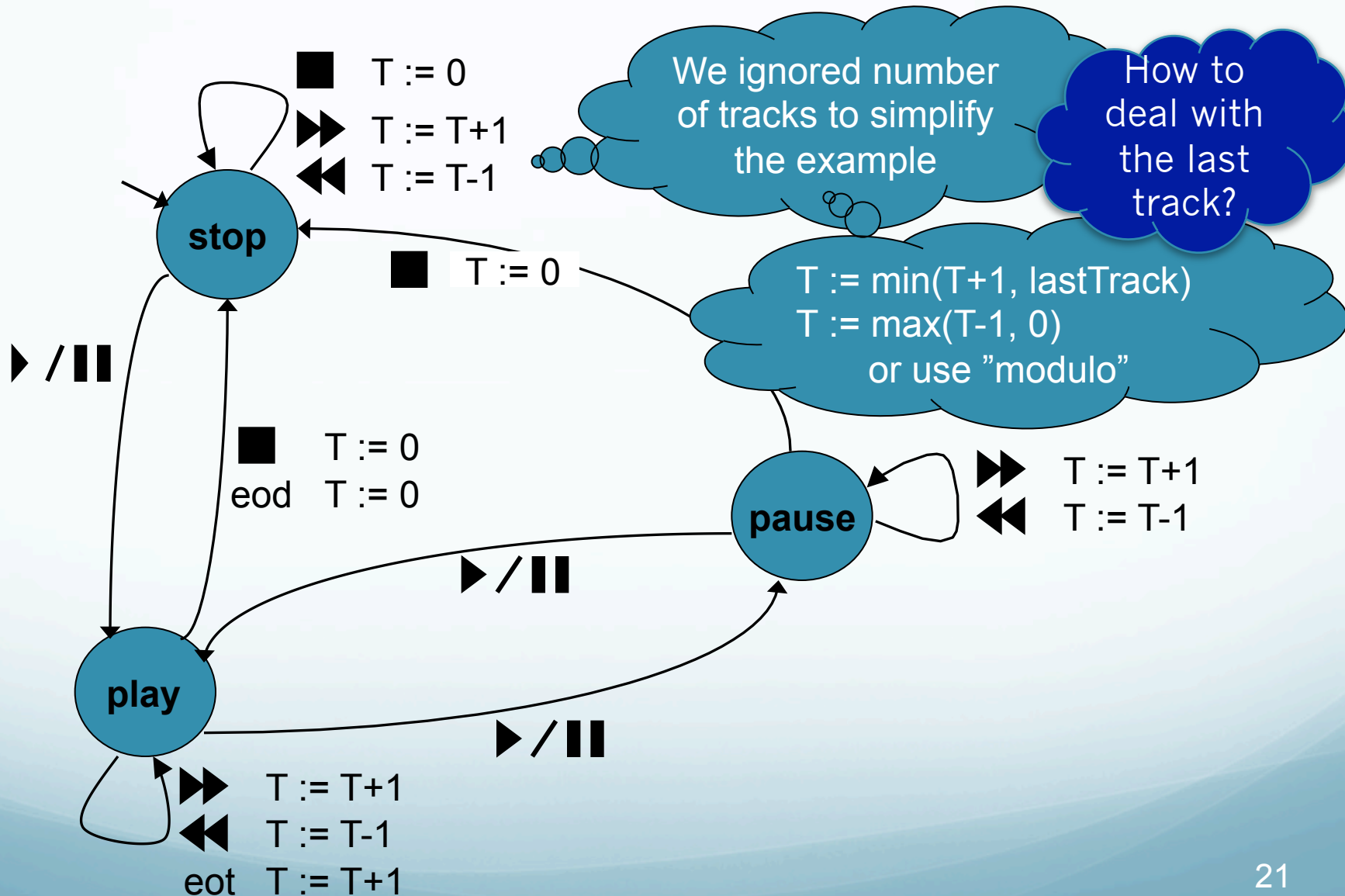
precondition((stopped, t), eod) -> false

precondition((paused, t), eod) -> false

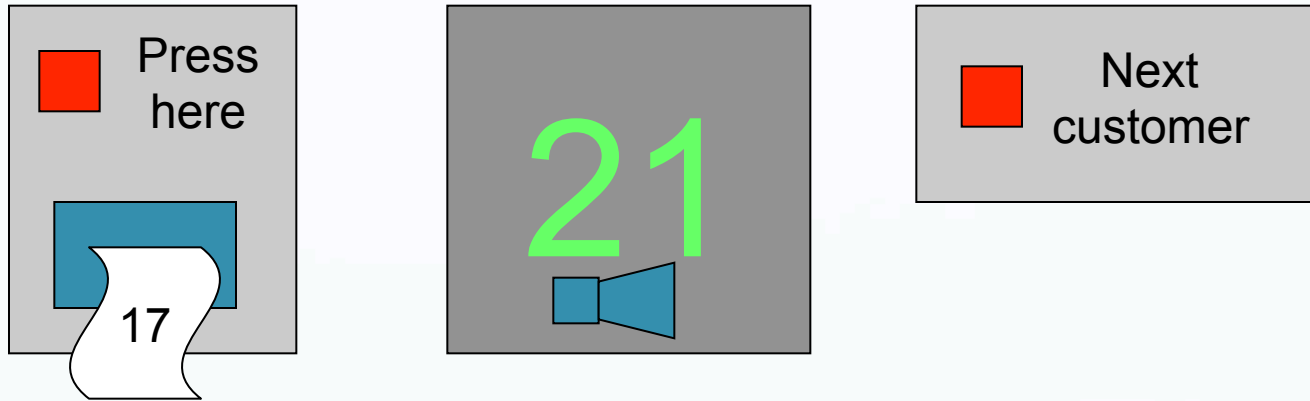
precondition((s,t), e) -> true

(for any other state *s*, track *t*, any other event *e* may happen?)

CD Player transitions

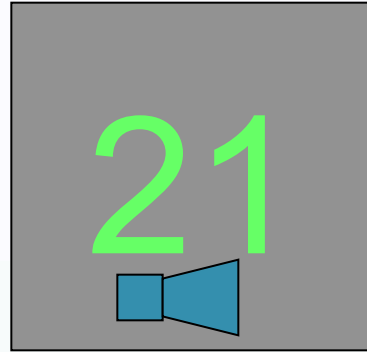
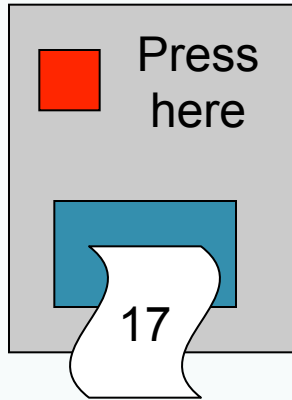


Turn ticket system



- 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



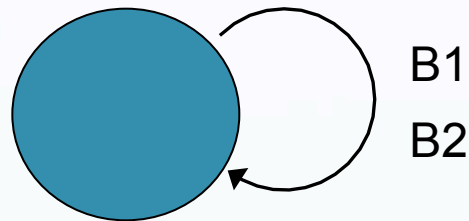
Informal specification

- 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

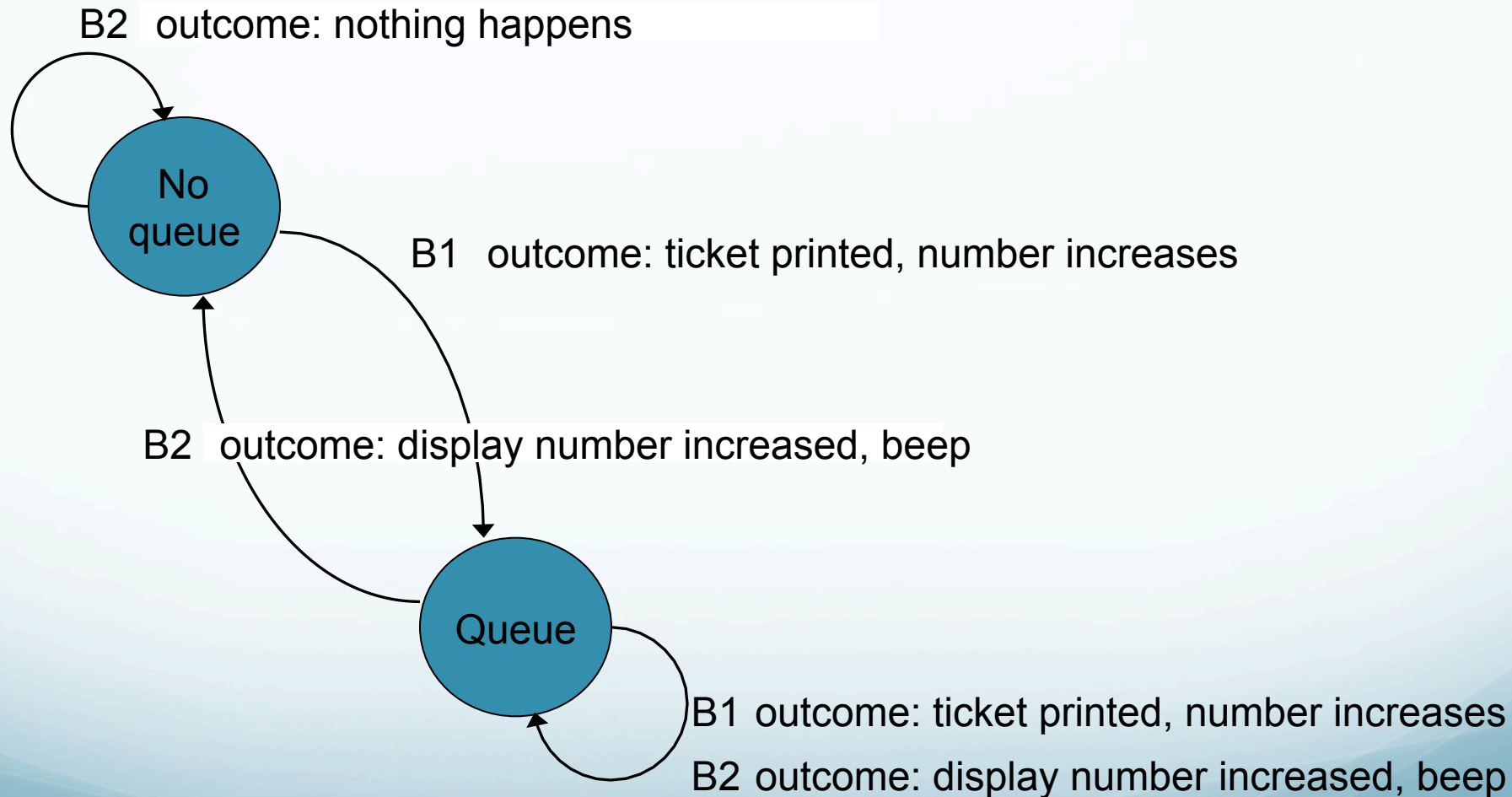
- Come up with a **finite-state machine (FSM)** that models this system
 - Many different variants exist with different levels of complexity and accuracy
- What are the limitations of your model?
- Come up with an **extended finite state machine (EFSM)** that models the system more accurately
 - Perhaps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

The simplest FSM representation of all



- This FSM models all systems with two events
- Hence, it is useless!

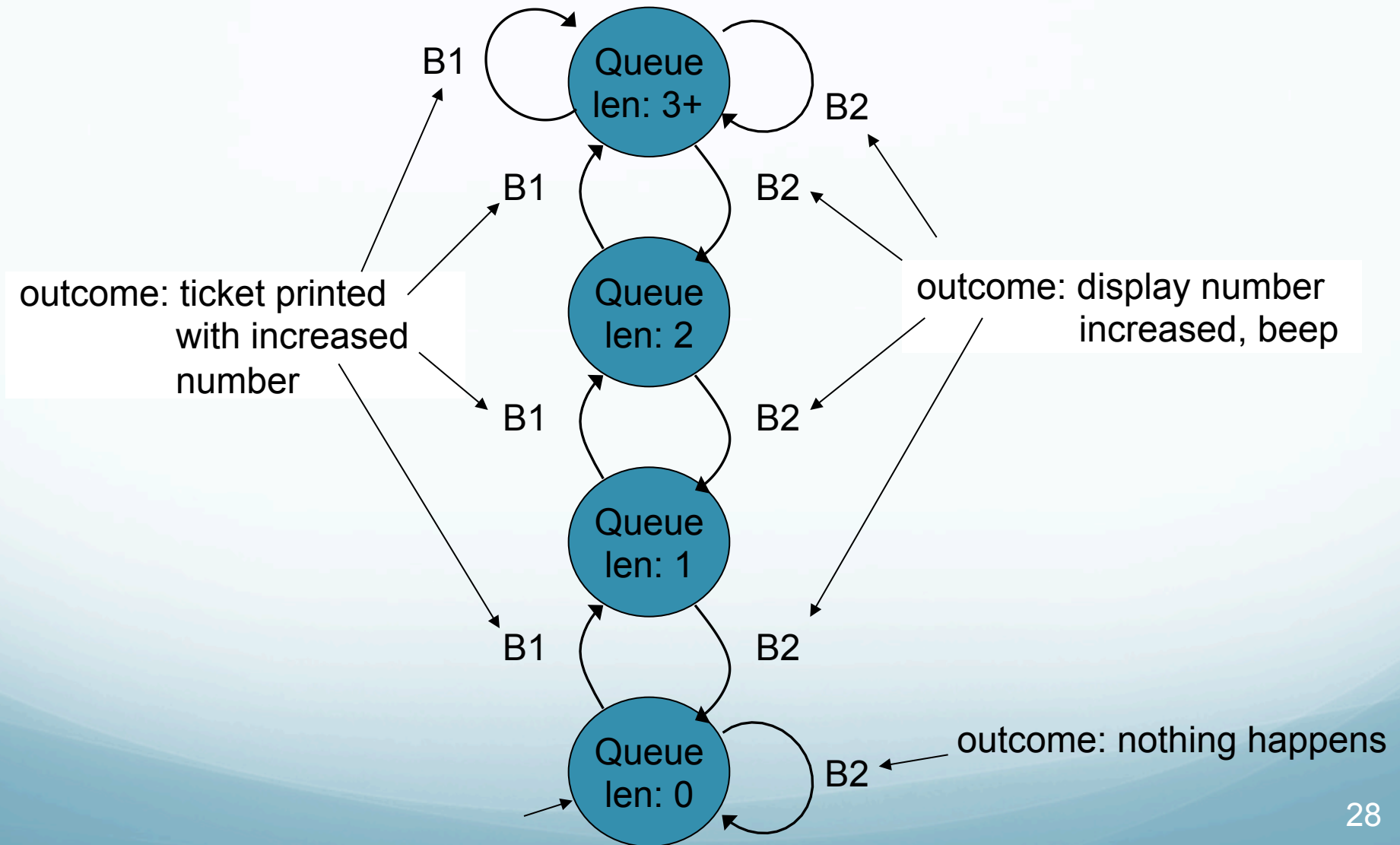
FSM representation (very simple)



Properties of this FSM

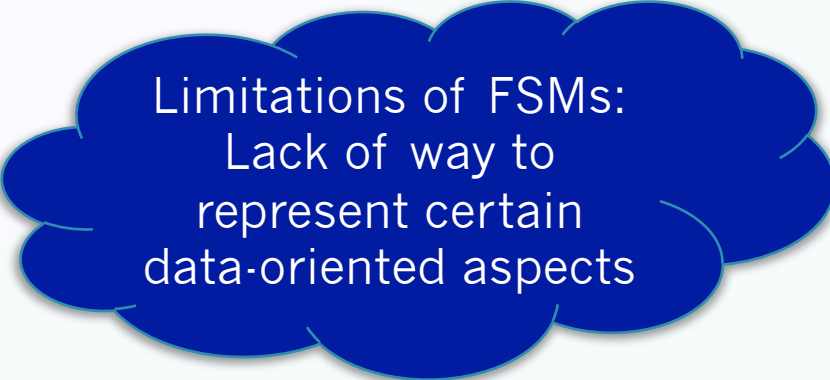
- Simple! (easy to understand, easy to come up with)
- Nondeterministic
 - (Why?)
- Can determine:
 - Correct behaviour of one B2 press after a B1
- Cannot determine:
 - Correct behaviour of multiple B2 presses
 - Exact numbers on tickets and display
- Useful for:
 - Understanding
 - Writing some testcases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

FSM representation (bounded queue)



Properties of this FSM

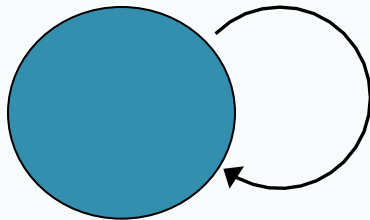
- Still rather simple
- Still nondeterministic (in top state)
- Can determine
 - Correct behaviour as long as not more than 2 people in queue
- Cannot determine
 - Correct behaviour with more than 2 people in queue
 - Exact numbers on tickets and display
- Useful for
 - Understanding
 - Writing more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



Limitations of FSMs:
Lack of way to
represent certain
data-oriented aspects

EFSM representation 1

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



B1 $n := n+1$

Expected outcome: ticked printed with increased number

B2 if $n \geq 1$ then
 $n := n-1$;
else
 null;
fi

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: $P=0$, $Q=0$



Quite detailed
description
encoded in the
transitions...

- Next state function:
 - B1: $P := P+1 \bmod 1000$
 - Expected outcome: ticket printed with number P
 - B2: if $P=Q$ then
 - null; // expected outcome: nothing happens
 - else
 - $Q=Q+1 \bmod 1000$;
 - // 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

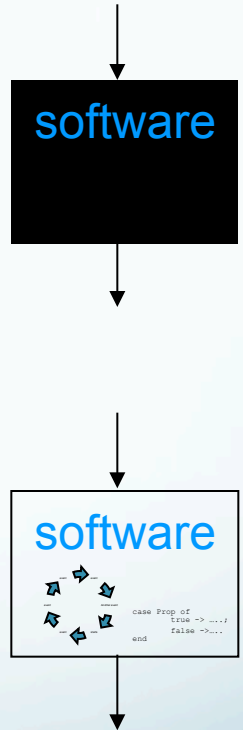
Black box and white box testing

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.

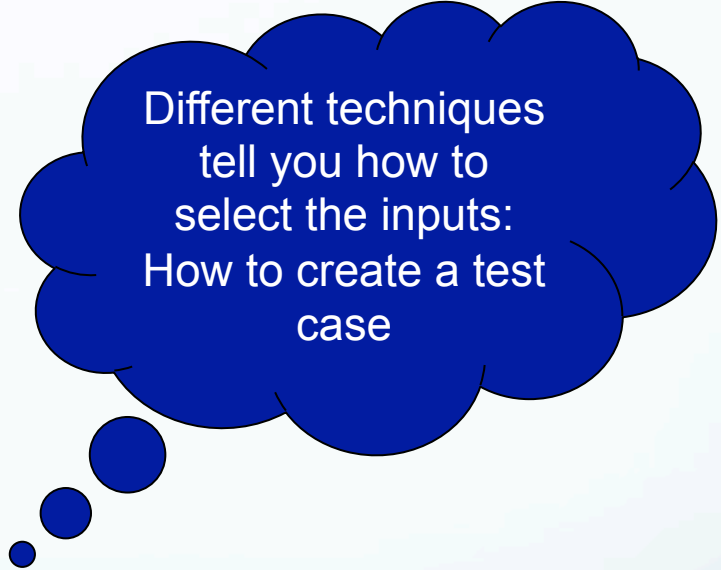
A test is performed by sending an **input value** and observing the **output** and internals while explicitly *using knowledge about the test object internals.*



Black Box testing

Techniques

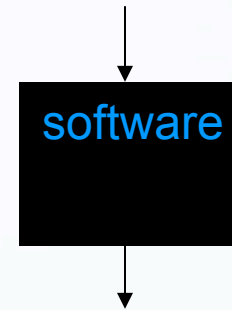
- Random Testing
- Equivalence Class Partitioning
- Boundary Value Analysis
- Cause and Effect Graphing
- State Transition Testing
- Error Guessing
- Use case testing ...



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

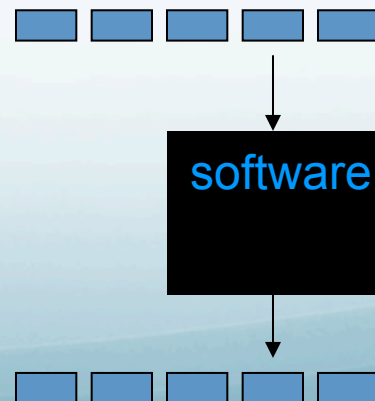
Misleading...

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

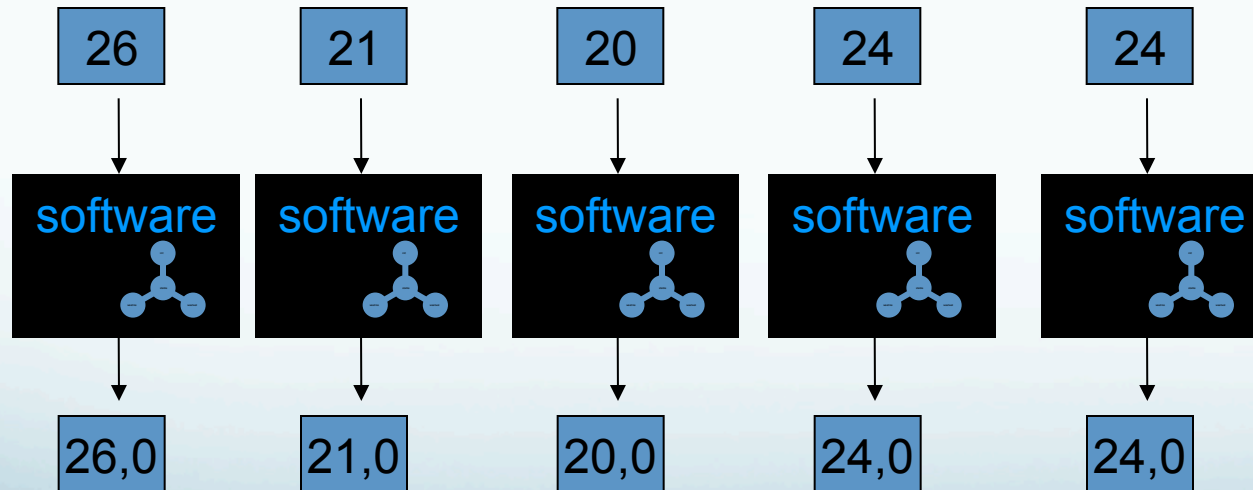
In case the test object has memory, the expected output **depends on the history!**



"Box" has state

Test case: Start the test object, send 1 value;

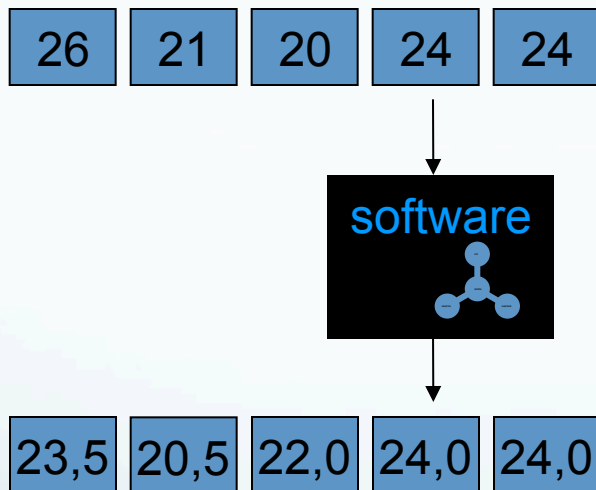
Execute 5 test cases



"Box" has state

Test case: Start the test object, send 5 values;

Execute 1 test case



Specification:

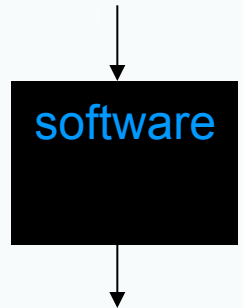
Return **average temperature** over today and yesterday

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

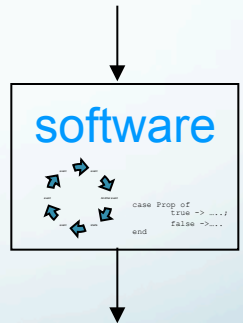
Black box testing: Test tactic in which the test object is addressed as a box one **cannot** open.

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

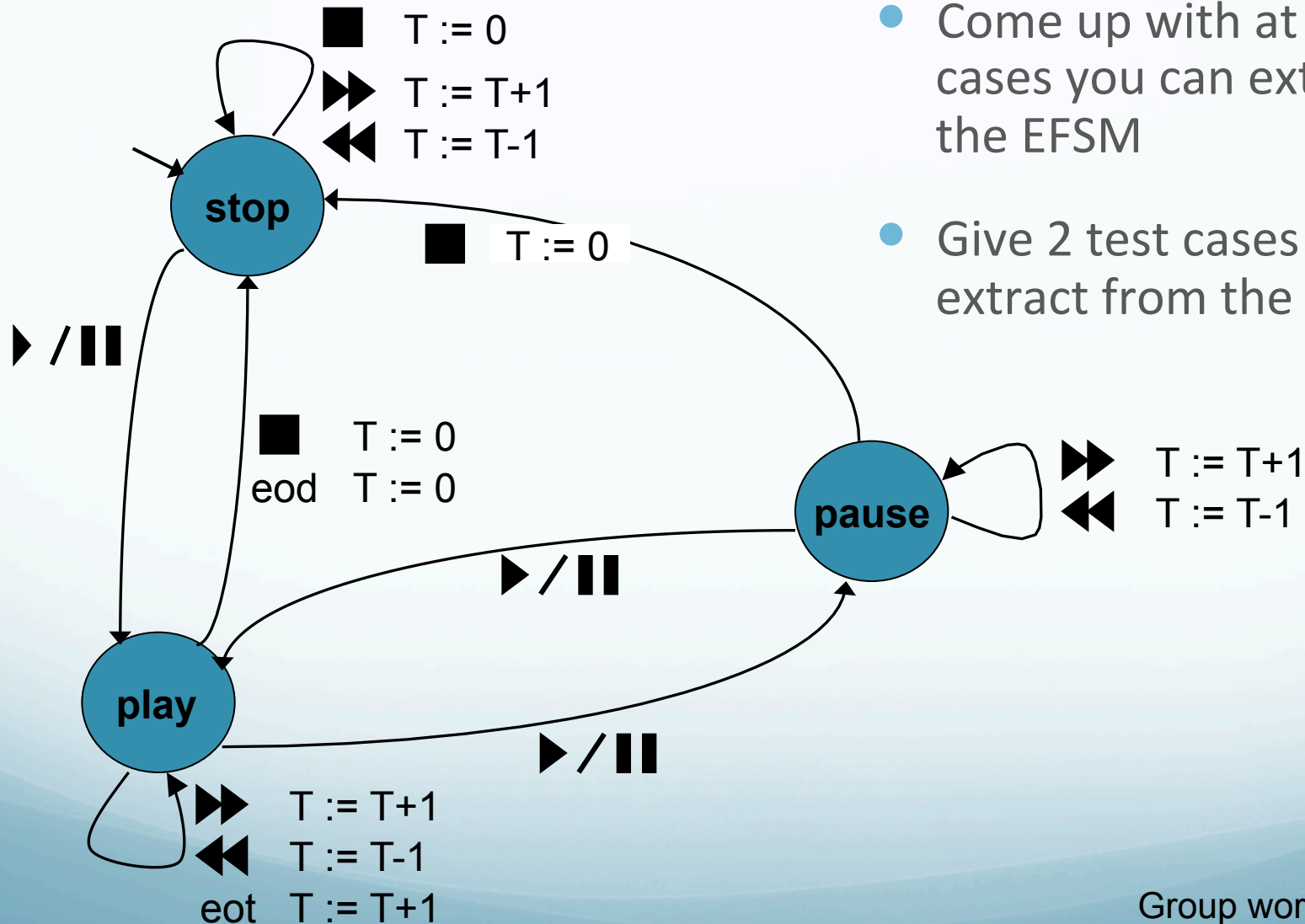
Creating test cases

- **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**
 - Use your experience and intuition... 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, $n \leq m$
 - 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



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?
 - Sw Engineers: ",", 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 identify the problem and find a solution?

- **Specification** was semi-formal (rather informal)
FSM
- There was a transition with condition "A, B . . ."
 - Sw Engineers: " , " was an OR but subcontractors interpreted as an AND

Btw, not found
with testing but
by using Formal
Methods

Next lecture

White Box Testing and Coverage