Finite State Machines

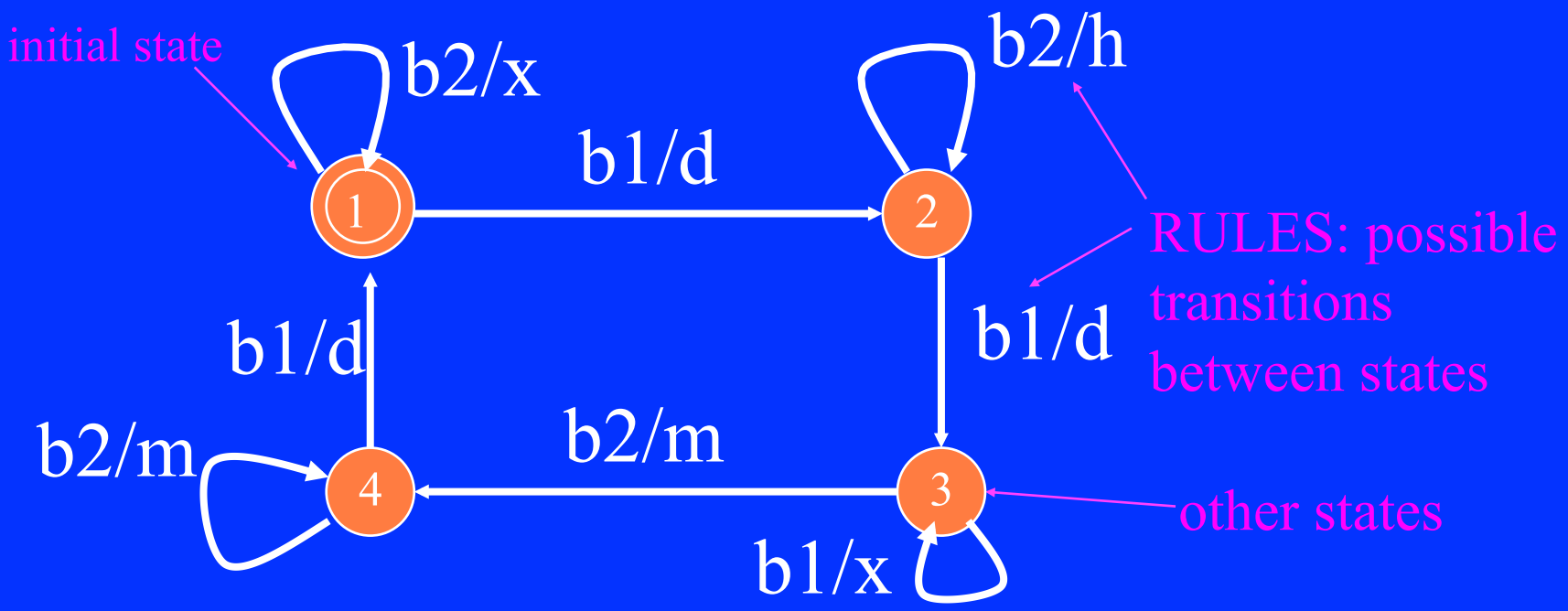
- FSMs model the dynamic behaviour of a system
- STATES describe a condition of the system
  - e.g. light-on, daytime, running, waiting
  - denoted by a circle, may be labelled with the state name. Initial state has a double circle.
- TRANSITIONS describe a change of state
  - may be triggered by an event, some state condition or the passing of time
  - a state may have 0, 1 or more outgoing transitions and may have self loop transitions

Types of FSM

- FSMs have proved useful in many branches of computer science, and there are many different types of FSM e.g.
- *UML statecharts:* transitions labelled with a string denoting an event, condition or time (see B&D p62)
- *Mealy Machines:* transitions labelled with a pair of events **i/o** naming an input **i** and expected output **o**
- Other types of FSM are labelled with expressions and assignments to represent programs

Mealy FSM example

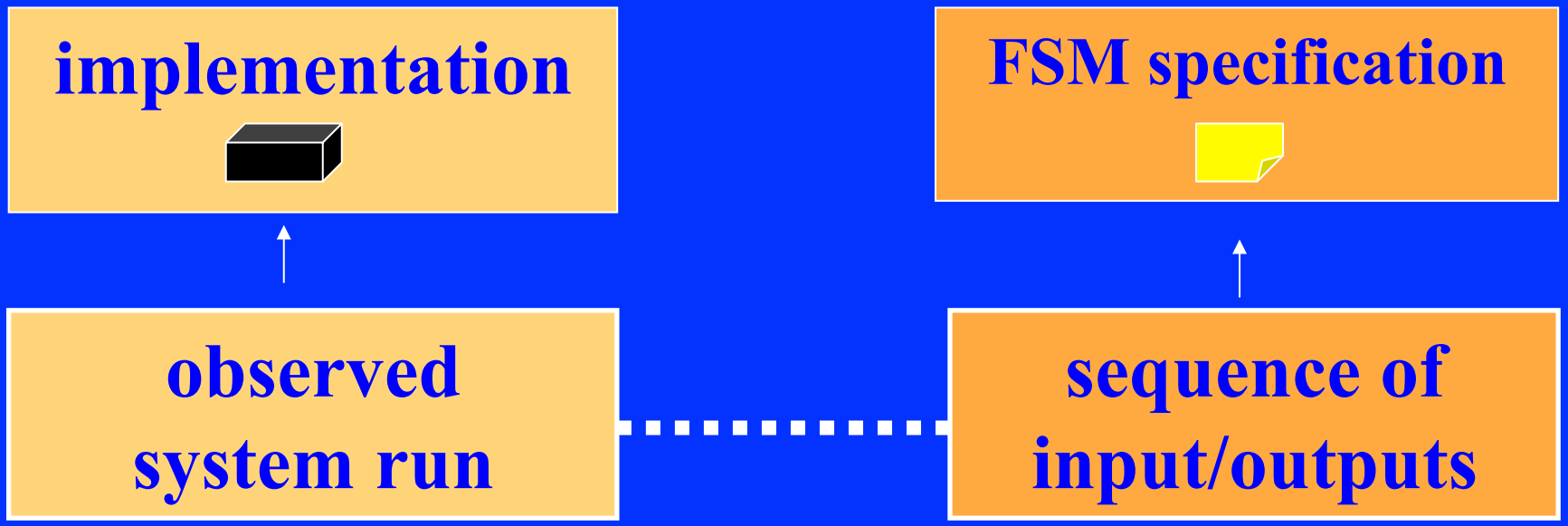
- **We will use Mealy FSMs for conformance testing**
- transitions are labelled with input/output pairs
- Example for a digital watch (see B&D ch 2)
  - inputs: button 1 pressed (b1), button 2 pressed (b2)
  - outputs: incr hours (h), incr minutes (m), display full time (d), beep(x) for unexpected input



Identifying a FSM by its outputs

- To test that an implementation **conforms** to a FSM specification, check that for each input sequence, the implementation delivers the same output sequence as the specification
- Q: for input sequence b1,b2,b2,b1,b1 what is the output sequence of the watch FSM?
- Q: can you find a test input sequence (or more than one sequence) which tests **every** transition?
- Q: can you find a test input sequence which uniquely identifies state 2 ? (that is, whose output sequence is not matched by any other state)

A Fundamental Assumption about Observations & Traces



The Conformance Test Problem

- Suppose we have
  - **I** a (**black box**) implementation &
  - **S** a formal FSM specification for **I**
- The problem is to construct
  - a **finite** set of test experiments **T**
- Such that
  - if **I≃S** then **I passes every test in T** &
  - if **not I≃S** then **I fails some test in T**

Assumptions Made

- Each FSM state must have an output for every possible input: FSM is ***completely specified***
- For each input from a given state there is a unique output value and state: FSM is ***deterministic***
- There are no redundant states: FSM is ***minimal***
- We shall ***assume*** that the implementation FSM has the ***same number of states*** as the specification FSM
- See reference list papers for some things to do when these assumptions are not reasonable

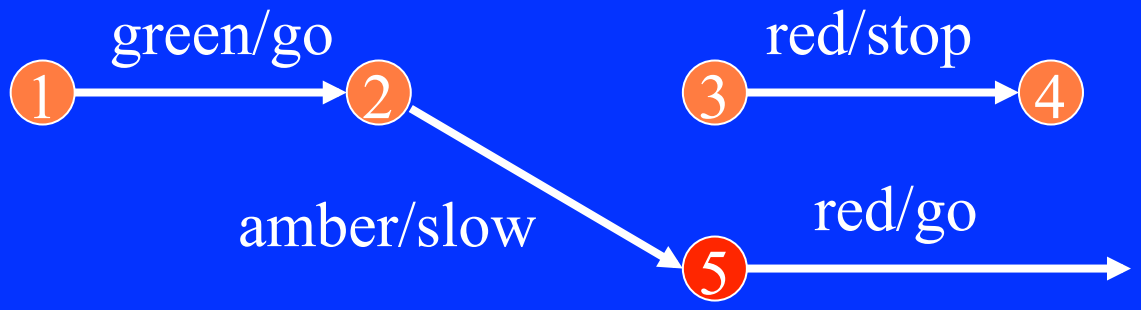
Action Errors

specification

implementation

Transfer Errors

specification



implementation
has correct output
but future errors

Worked Example: Specification of a comment printer

Input consists of the characters * o ( )
o stands for any character except * or (or)
Print only comments, where a comment is an input subsequence enclosed by (*
on the left and *) on the right.
A comment may contain other (*s but not *)s

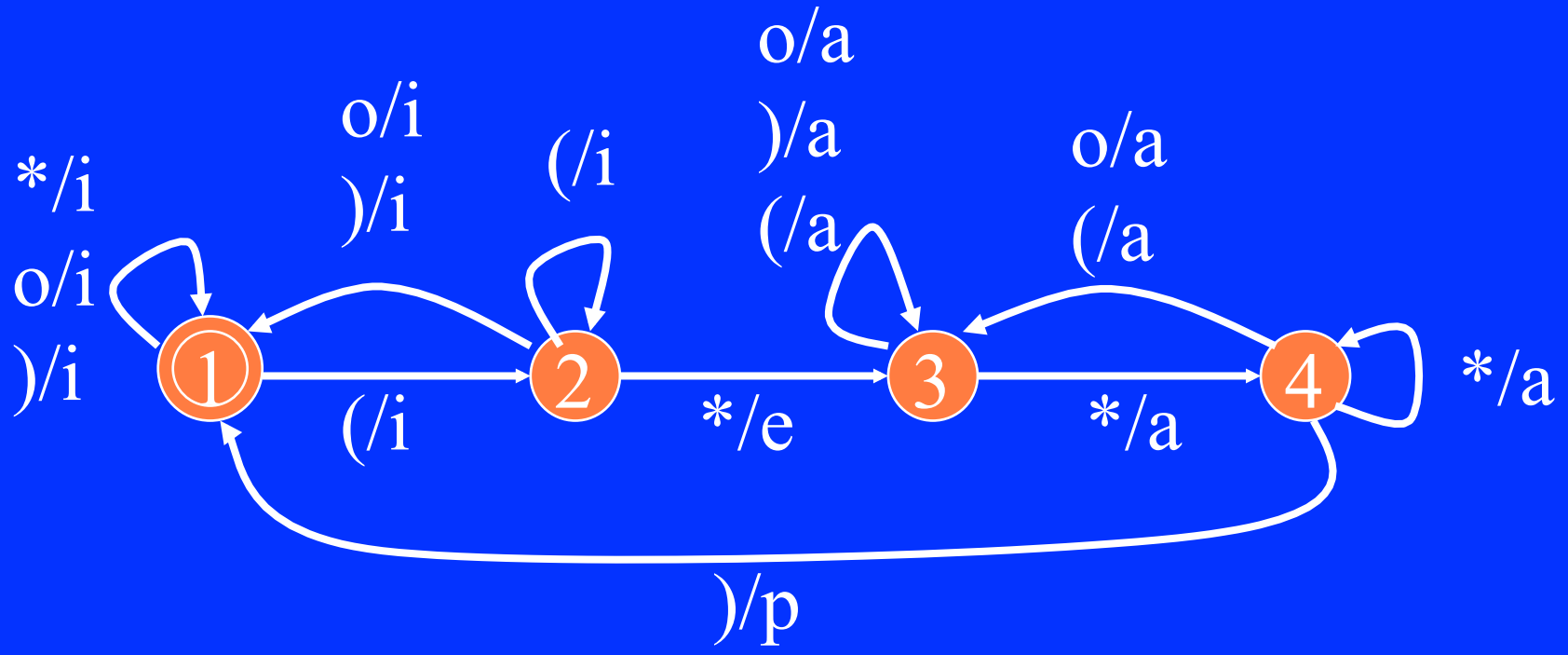
Note: there is an error in this example in Chow's paper

Comment Printer outputs

OUTPUT	INTERPRETATION
i(gnore)	null action
e(mpty-bf)	set buffer to empty
a(cc-bf)	add current input to the buffer
p(rint-bf)	remove last char added to the buffer and print out contents

Assume that the buffer stores only characters and that its length is unbounded

A Comment Printer FSM



Ex: Give the output sequences generated by this FSM for the input sequences o))o(*oo**)* *and* (*((*)

Ex at home: Try also the input: int i (* this is an int. *)

How to Generate Test Cases (1)

- The set of all test sequences required to test an FSM is the concatenation of two sets of sequences **P** and **Z**
- All test sequences must start from the INITIAL state

- **P** is any set of input sequences such that
  - for every transition from state **Ai** to state **Aj** & input **x**
  - **P** contains a sequence of inputs **p.x** where
  - **p** forces the machine into state **Ai** from its initial state
  - **P** also includes the empty input sequence
- Construct **P** by starting at the initial state and at each stage adding edges which lead from the current frontier states until all edges have been covered

Example: P for the CP

Edge	P	Edge	P
1 */i 1	*	3 */a 4	(* *
1 o/i 1	o	3 o/a 3	(* o
1)/i 1	)	3)/a 3	(*)
1 (/i 2	(	3 (/a 3	(* (
2 */e 3	(*	4 */a 4	(* * *
2 o/i 1	(o	4 o/a 3	(* * o
2)/i 1	( )	4)/p 1	(* *)
2 (/i 2	(	4 (/a 3	(* * (

How to Generate Test Cases (2)

- Z is used to check that the implementation state reached is the same as the specification state
- If for an input the implementation gives an *unexpected* output then we know that **I** is incorrect
- However, what if the implementation gives the *right* output but then goes on to produce incorrect outputs in the future?
- A set Z which can distinguish between every state of an FSM by that state's response to certain input sequences is called a **characterization set** for the design

A characterization set for the CP

states \ inputs	(	)	*	o
1	i	i	i	i
2	i	i	e	i
3	a	a	a	a
4	a	p	a	a

$Z = \{), * \}$

CHECK that the 2 single element sequences,) and *, are sufficient to distinguish between any two states in the specification FSM

Sometimes sequences of more than one element are needed

How to Generate Test Cases (3)

- Now that we have constructed the sets P and Z, the set of all test cases for a given FSM is given by concatenating (joining together) each sequence in P with each sequence in Z

- The test suite for the CP example is built from

- P = { ., *, o,), (, (*, (o, (), ((, (**, (*o, (*), (*(, (***, (**o, (**), (**(}
- Z = {), * }

How to Generate Test Cases (4)

- P.Z is) and * from (empty sequence).Z with
- *) o))) () and ** o*)* (* and
- (*) (o) ()) (() and (** (o* ()* ((* and
- (**) (*o) (*)) (*() and (*** (*o* (*)* (*(* and
- (***) (**o) (**)) (**() and (**** (**o* (**)* (**(*

- but), *, (*, (** and (*** are included in longer sequences and so finally
- P.Z = { *) , o),)), (), ** , o*,)*,
  (*), (o) , ()), (((, (o* , ()* , ((* ,
  (**) , (*o) , (*)) , (*() , (*o* , (*)*, (*(* ,
  (***) , (**o) , (**)), (**(), (**** , (**o* , (**)*, (**(*
  }

- 29 test cases are needed from the possible 32+2 tests for this FSM with 16 edges, 4 inputs, 4 outputs and 4 states. In general, up to N.M tests are needed for an FSM with N edges whose states can be distinguished by a set of size M

Type of Implementation Faults which can be Detected

- **Action Errors** (see slide 9)
  - There is an edge from state `s` which is in both **S** and **I**, so that given input `i`, **S** outputs `o1` but **I** outputs a *different* value `o2`
- **Transfer Errors** (see slide 10)
  - **S** and **I** give output the same value given input `i` in state `s`, but afterwards **S** has reached state `s1` but **I** has reached a *different state* `s2`
- **Doesn't** detect **Extra States** in the implementation

Conformance Test Summary

- Chow's WP Method shows how to generate test suites for implementations which can be specified by Mealy FSMs
- FSM specs must be completely specified and minimal
- We have also assumed that the implementation has no more states than the specification (this assumption is not essential but it makes life easier)
- **T = P.Z** is a finite set of test cases with the property that

  If **I≃S** then **I passes every test in T** &

  If **not I≃S** then **I fails some test in T**
- The test method is, thus, both **reliable** and **valid**

Further Reading

- Chow, Tsun. S.:
  Testing Software Design Modeled by Finite-State Machines
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  Design and Validation of Computer Protocols
  Prentice Hall (1991)
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  Conformance Tests for Real-Time Systems with Timed Automata Specifications
  Formal Aspects of Computing Journal, 12: 350-371 (2000)
- Hennessey, M.:
  Algebraic Theory of Processes
  MIT Press (1988)