Internal DSL style

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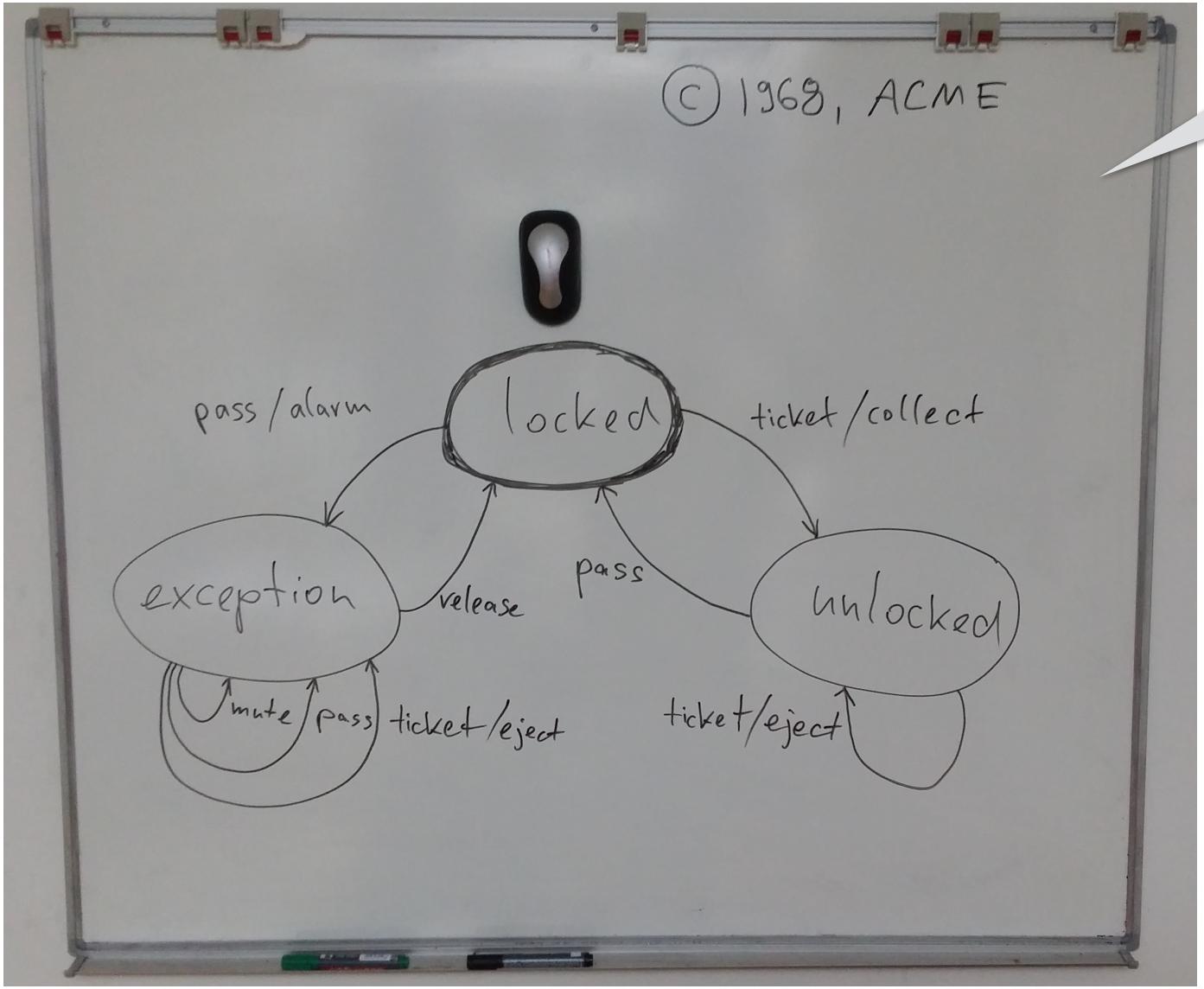
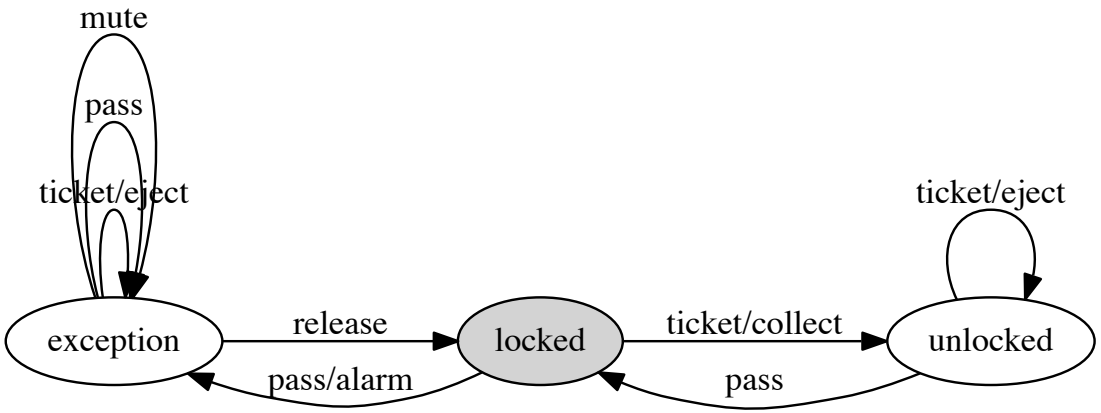
A DSL for finite state machines (FSMs)



A FSM for a 'turnstile' in a metro system

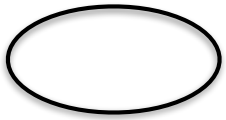
Imagine the FSM language (FSML) to have started on the black/whiteboard a long time ago.

Concepts of FSML illustrated for the turnstile FSM



States

locked The turnstile is locked. No passenger is allowed to pass.
unlocked The turnstile is unlocked. A passenger may pass.
exception A problem has occurred and metro personnel needs to intervene.



Events

ticket A passenger inserts a ticket into the card reader.
pass A passenger passes the turnstile as noticed by a sensor.
mute Metro personnel turns off alarm after exception.
release Metro personnel turns on normal operation again.

e/a

Actions

collect The ticket is collected by the card reader.
eject The ticket is ejected by the card reader.
alarm An alarm is turned on and metro personnel is requested.

e/**a**

Transitions

Semantics (I/O behavior) of FSML illustrated for the turnstile FSM

Input (= sequence of events)

ticket	*A ticket is inserted. (The turnstile is unlocked, thus.)*
ticket	*Another ticket is inserted. (The superflous ticket is ejected.)*
pass	*Someone passes the turnstile. (This is Ok.)*
pass	*Someone passes the turnstile. (This triggers alarm.)*

Output (= sequence of actions)

collect	*The inserted ticket is collected.*
eject	*A ticket inserted in unlocked state is ejected.*
alarm	*An attempt to pass in locked state triggers alarm.*

DSL implementation in different ‘styles’

- **External DSL**:

  Designated parser, checker, interpreter, compiler

- **Internal DSL**:

  Implementation as library using host language features

Our focus for now*!*

N.B.: This is a gross oversimplification.
There are options or hybrids using extensible languages, extensible compilers, metaprogramming systems, and language workbenches.

We are going to do here …

Internal DSL style

with 

and 

libraries

N.B.: If we were using C++, Scheme, Haskell, or others for internal DSL implementation, additional or different techniques could or should be leveraged, e.g., operator overloading, macros, or templates.

```
turnstile = new Fsm();
State s = new State();
s.setStateid("locked");
s.setInitial(true);
turnstile.getStates().add(s);
s = new State();
s.setStateid("unlocked");
turnstile.getStates().add(s);
s = new State();
s.setStateid("exception");
turnstile.getStates().add(s);
Transition t = new Transition();
t.setSource("locked");
t.setEvent("ticket");
t.setAction("collect");
t.setTarget("unlocked");
turnstile.getTransitions().add(t);
t = new Transition();
... add more transitions ...
```

‘Imperative’ Java API

N.B.: Arguably this was common style until perhaps 200?. Even today, this sort of code may still be written.

Java API with functional constructors

```
turnstile = new Fsm();
turnstile.getStates().add(new State("locked", true));
turnstile.getStates().add(new State("unlocked"));
turnstile.getStates().add(new State("exception"));
turnstile.getTransitions().add(new Transition("locked", "ticket", "collect", "unlocked"));
turnstile.getTransitions().add(new Transition("locked", "pass", "alarm", "exception"));
... add more transitions ...
```

N.B.: Functional constructors have been used by C++ and Java et al. programmers for a long time, but they are insufficient to avoid repetitive code and to hide the internal representation.

Basic Java object model including functional constructors

```
public class Fsm {
   private List<State> states = new LinkedList<>();
   private List<Transition> transitions = new LinkedList<>();
   public List<State> getStates() { return states; }
   public List<Transition> getTransitions() { return transitions; }
}
public class State {
   private String id;
   private boolean initial;
   public String getStateid() { return id; }
   public void setStateid(String state) { this.id = state; }
   public boolean isInitial() { return initial; }
   public void setInitial(boolean initial) { this.initial = initial; }
   public State() { }
   public State(String id) { this.id = id; }
   public State(String id, boolean initial) { this.id = id; this.initial = initial; }
}
public class Transition {
   private String source;
   private String event;
   private String action;
```

It's easy,

but not what we want.

```
  private String id;
  private boolean initial;
  public String getStateid() { return id; }
  public void setStateid(String state) { this.id = state; }
  public boolean isInitial() { return initial; }
  public void setInitial(boolean initial) { this.initial = initial; }
  public State() { }
  public State(String id) { this.id = id; }
  public State(String id, boolean initial) { this.id = id; this.initial = initial; }
}
public class Transition {
  private String source;
  private String event;
  private String action;
  private String target;
  ... getters and setters ...
  public Transition() { }
  public Transition(String source, String event, String action, String target) {
    this.source = source;
    this.event = event;
    this.action = action;
    this.target = target;
  }
}
```

Use of a **fluent API** in Java

```
Fsm turnstile =
  fsm()
    .addState("locked")
      .addTransition("ticket", "collect", "unlocked")
      .addTransition("pass", "alarm", "exception")
    .addState("unlocked")
      .addTransition("ticket", "eject", "unlocked")
      .addTransition("pass", null, "locked")
    .addState("exception")
      .addTransition("ticket", "eject", "exception")
      .addTransition("pass", null, "exception")
      .addTransition("mute", null, "exception")
      .addTransition("release", null, "locked");
```

Leveraged techniques:

- Factory methods
- Method chaining
- Implicit parameters
- Conventions (defaults)

N.B.: The current state is maintained along the way.

The state declared first is assumed to be the initial one.

The representation is not revealed—no constructors are used.

Use of a **fluent API** in Python

```
turnstile = Fsm() \
    .addState("locked") \
        .addTransition("ticket", "collect", "unlocked") \
        .addTransition("pass", "alarm", "exception") \
    .addState("unlocked") \
        .addTransition("ticket", "eject", "unlocked") \
        .addTransition("pass", None, "locked") \
    .addState("exception") \
        .addTransition("ticket", "eject", "exception") \
        .addTransition("pass", None, "exception") \
        .addTransition("mute", None, "exception") \
        .addTransition("release", None, "locked")
```

Leveraged techniques:

- Factory methods
- Method chaining
- Implicit parameters
- Conventions (defaults)

N.B.: If we were using C++, Scheme, Haskell, or others for internal DSL implementation, additional or different techniques could or should be leveraged, e.g., operator overloading, macros, or templates.

Definition of **fluent API** in Java

```
public interface Fsm {
  public Fsm addState(String state);
  public Fsm addTransition(String event, String action, String target);
  public String getInitial();
  public ActionStatePair makeTransition(String state, String event);
}
```

Interface

```
public class ActionStatePair {
  public String action;
  public String state;
}
```

Helper type

N.B.: This interface does not expose the internal representation.
The interface does not just cover fluent construction;
it also covers ‘observation’ of the opaque representation.

Implementation of **fluent API** in Java

```
public class FsmImpl implements Fsm {
  private String initial; // the initial state
  private String current; // the "current" state
  // A cascaded map for maintaining states and transitions
  private HashMap<String, HashMap<String, ActionStatePair>> fsm =
      new HashMap<>();
  private FsmImpl() { }
  // Construct FSM object
  public static Fsm fsm() { return new FsmImpl(); }
  // Add state and set it as current state
  public Fsm addState(String id) {
    // First state is initial state
    if (initial == null) initial = id;
    // Remember state for subsequent transitions
    this.current = id;
    if (fsm.containsKey(id)) throw new FsmIDistinctIdsException();
    fsm.put(id, new HashMap<String, ActionStatePair>());
    return this;
  }
  // Add transition for current state
  public Fsm addTransition(String event, String action, String target) { ...
```

```
    if (fsm.containsKey(id)) throw new FsmIDistinctIdsException();
    fsm.put(id, new HashMap<String, ActionStatePair>());
    return this;
  }
  // Add transition for current state
  public Fsm addTransition(String event, String action, String target) {
    if (fsm.get(current).containsKey(event)) throw new FsmIDeterminismException();
    ActionStatePair pair = new ActionStatePair();
    pair.action = action;
    pair.state = target;
    fsm.get(current).put(event, pair);
    return this;
  }
  // Getter for initial state
  public String getInitial() {
    return initial;
  }
  // Make transition
  public ActionStatePair makeTransition(String state, String event) {
    if (!fsm.containsKey(state)) throw new FsmIResolutionException();
    if (!fsm.get(state).containsKey(event)) throw new FsmIInfeasibleEventException();
    return fsm.get(state).get(event);
  }
}
```

A *JUnit* test case for simulation

```
public class FluentTest {

  private static final String[] input =
    {"ticket", "ticket", "pass", "pass", "ticket", "mute", "release"};
  private static final String[] output =
    {"collect", "eject", "alarm", "eject"};

  @Test
  public void runSample() {
    assertArrayEquals(output, run(Sample.turnstile, input));
  }
}
```

Sample input

Expected output

FSML interpreter

N.B.: This is how a Java programmer (a DSL user) would document a use case of a specific FSM (and validate intuitions).

An interpreter (a 'simulator') in Java

```
public class FsmInterpreter {
  public static String[] run(Fsm fsm, String[] input) {
    ArrayList<String> output = new ArrayList<>();
    String state = fsm.getInitial();
    for (String event : input) {
      ActionStatePair pair = fsm.makeTransition(state, event);
      if (pair.action != null) output.add(pair.action);
      state = pair.state;
    }
    return output.toArray(new String[output.size()]);
  }
}
```

N.B.: The interpreter essentially models the dynamic semantics of FSML. This is a non-interactive interpreter. In practice, an interactive DSL implementation may be required.

Implementation of **fluent API** in Python

```
class Fsm():
    def __init__(self):
      self.fsm = defaultdict(list)
      self.current = None
    def addState(self, id):
        return self.addStateNoDefault(self.current is None, id)
    def addStateNoDefault(self, initial, id):
        if id in self.fsm[id]: raise FsmIDistinctIdsException;
        self.stateObject = dict()
        self.stateObject['transitions'] = defaultdict(list)
        self.stateObject['initial'] = initial
        self.fsm[id] += [self.stateObject]
        self.current = id
        return self
    def addTransition(self, event, action, target):
        if event in self.stateObject['transitions']: raise FsmIDeterminismException;
        self.stateObject['transitions'][event] += \
          [(action, self.current if target is None else target)]
        return self
```

N.B.: no high-level API is provided for 'observation'; one would access the dictionary directly.

An interpreter (a 'simulator') in Python

```
def run(fsm, input):
    # Determine initial state
    for id, [decl] in fsm.iteritems():
        if decl["initial"]:
            current = decl
            break
    # Consume input; produce output
    output = []
    while input:
        event = input.pop(0)
        if event not in current["transitions"]: raise FsmlInfeasibleEventException
        else:
            [(action, target)] = current["transitions"][event]
            if action is not None: output.append(action)
            if target not in fsm: raise FsmlResolutionException
            [current] = fsm[target]
    return output
```

N.B.: When compared to the Java-based interpreter, we access directly the presentation.

‘Minimum’ DSL implementation

- ✓ Syntax (fluent API for internal DSL)
- ✓ (Dynamic) semantics (e.g., by means on an interpreter)
- \- Well-formedness / -typedness (aka static semantics)

N.B.: Just like the interpreter, we implement a ‘well-formedness checker’ as functionality on top of (the API for) the internal DSL representation. (We could use a constraint language such as OCL.)

Well-formedness of FSMs

distinctStateIds The state ids of the state declarations must be distinct.
singleInitialState An FSM must have exactly one initial state.
deterministicTransitions The events must be distinct per state.
resolvableTargetStates The target state of each transition must be declared.
reachableStates All states must be reachable from the initial state.

```
resolutionNotOk = \
  Fsm() \
    .addState("stateA") \
      .addTransition("eventI", "actionI", "stateB") \
      .addTransition("eventII", "actionII", "stateC") \
    .addState("stateB")
```

N.B.: This sample violates *resolvableTargetStates*.

N.B.: a violated *resolvableTargetStates* can (should) be detected even before running an FSM on a specific input.

Python-based well-formedness checker

```
def ok(fsm):
    for fun in [
            distinctStateIds,
            singleInitialState,
            deterministicTransitions,
            resolvableTargetStates,
            reachableStates ] : fun(fsm)

def distinctStateIds(fsm):
    for state, decls in fsm.iteritems():
        if not len(decls) == 1: raise FsmlDistinctIdsException()

def singleInitialState(fsm):
    initials = [initial for initial, [decl] in fsm.iteritems() if decl["initial"]]
    if not len(initials) == 1: raise FsmlSingleInitialException()

def deterministicTransitions(fsm):
    for state, [decl] in fsm.iteritems():
        for event, transitions in decl["transitions"].iteritems():
            if not len(transitions) == 1: raise FsmlDeterminismException()

def resolvableTargetStates(fsm):  ...
```

N.B.: Violations of *distinctStateIds* and *deterministicTransitions* can be detected during construction, but we may need explicit checks if we also accommodate ‘serialization’.

```
def singleInitialState(fsm):
    initials = [initial for initial, [decl] in fsm.iteritems() if decl["initial"]]
    if not len(initials) == 1: raise FsmlSingleInitialException()

def deterministicTransitions(fsm):
    for state, [decl] in fsm.iteritems():
        for event, transitions in decl["transitions"].iteritems():
            if not len(transitions) == 1: raise FsmlDeterminismException()

def resolvableTargetStates(fsm):
    for _, [decl] in fsm.iteritems():
        for _, transitions in decl["transitions"].iteritems():
            for (_, target) in transitions:
                if not target in fsm: raise FsmlResolutionException()

def reachableStates(fsm):
    for initial, [decl] in fsm.iteritems():
        if decl["initial"]:
            reachables = set([initial])
            chaseStates(initial, fsm, reachables)
    if not reachables == set(fsm.keys()): raise FsmlReachabilityException()

# Helper for recursive closure of reachable states
def chaseStates(source, fsm, states): ...
```

Online resources

YAS' GitHub repository contains all code.

YAS (Yet Another SLR (Software Language Repository))

http://www.softlang.org/yas

See here specifically:

https://github.com/softlang/yas/tree/master/languages/FSML

Subdirectories Java and Python

The Software Languages Book

http://www.softlang.org/book

The topic is covered in Chapter 2.