The State Design Pattern

Readings: OOSC2 Chapter 20

EECS3311 A: Software Design
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Motivating Problem

Consider the reservation panel of an online booking system:

-- Enquiry on Flights --

Flight sought from: Toronto To: Zurich

Departure on or after: 23 June On or before: 24 June

Preferred airline (s):

Special requirements:

AVAILABLE FLIGHTS: 1

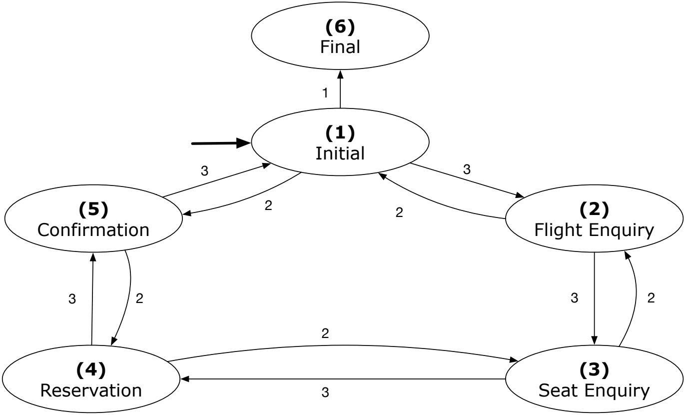
Flt#AA 42 Dep 8:25 Arr 7:45 Thru: Chicago

Choose next action:

- 0 – Exit
- 1 – Help
- 2 – Further enquiry
- 3 – Reserve a seat

State Transition Diagram

Characterize *interactive system* as: **1)** A set of *states*; and **2)** For each state, its list of *applicable transitions* (i.e., actions).
e.g., Above reservation system as a *finite state machine*:



Design Challenges

1. The state-transition graph may *large* and *sophisticated*.

   A large number N of states has $O(N^2)$ transitions

2. The graph structure is subject to *extensions*/*modifications*.

   e.g., To merge "(2) Flight Enquiry" and "(3) Seat Enquiry":

   Delete the state "(3) Seat Enquiry".
   Delete its 4 incoming/outgoing transitions.

   e.g., Add a new state "Dietary Requirements"

3. A *general solution* is needed for such *interactive systems*.

   e.g., taobao, eBay, amazon, etc.

A First Attempt

```
1_Initial_panel:
  -- Actions for Label 1.
2_Flight_Enquiry_panel:
  -- Actions for Label 2.
3_Seat_Enquiry_panel:
  -- Actions for Label 3.
4_Reservation_panel:
  -- Actions for Label 4.
5_Confirmation_panel:
  -- Actions for Label 5.
6_Final_panel:
  -- Actions for Label 6.
```

```
3_Seat_Enquiry_panel:
from
  Display Seat Enquiry Panel
until
  not (wrong answer or wrong choice)
do
  Read user's answer for current panel
  Read user's choice C for next step
  if wrong answer or wrong choice then
    Output error messages
  end
end
Process user's answer
case C in
  2: goto 2_Flight_Enquiry_panel
  3: goto 4_Reservation_panel
end
```

A First Attempt: Good Design?

- Runtime execution ≈ a ***"bowl of spaghetti"***.

  ⇒ The system's behaviour is hard to predict, trace, and debug.
- *Transitions* hardwired as system's ***central control structure***.

  ⇒ The system is vulnerable to changes/additions of states/transitions.
- All labelled blocks are largely similar in their code structures.

  ⇒ This design "***smells***" due to duplicates/repetitions!
- The branching structure of the design exactly corresponds to that of the specific *transition graph*.

  ⇒ The design is ***application-specific*** and *not reusable* for other interactive systems.

A Top-Down, Hierarchical Solution

- *Separation of Concern* Declare the *transition table* as a feature the system, rather than its central control structure:

```
transition (src: INTEGER; choice: INTEGER): INTEGER
    -- Return state by taking transition 'choice' from 'src' state.
  require valid_source_state: 1 ≤ src ≤ 6
          valid_choice: 1 ≤ choice ≤ 3
  ensure valid_target_state: 1 ≤ Result ≤ 6
```

- We may implement `transition` via a 2-D array.

SRC STATE \ CHOICE	1	2	3
1 (Initial)	6	5	2
2 (Flight Enquiry)	–	1	3
3 (Seat Enquiry)	–	2	4
4 (Reservation)	–	3	5
5 (Confirmation)	–	4	1
6 (Final)	–	–	–

choice

state	*1*	*2*	*3*
1	**6**	**5**	**2**
2		**1**	**3**
3		**2**	**4**
4		**3**	**5**
5		**4**	**1**
6			

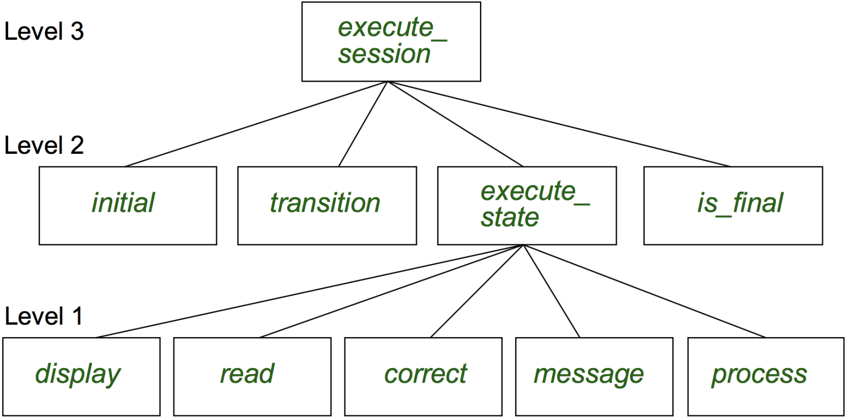
Hierarchical Solution: Good Design?

- This is a more general solution.

  ∵ *State transitions* are **separated** from the system's *central control structure*.

  ⇒ **Reusable** for another interactive system by making changes only to the `transition` feature.
- How does the *central control structure* look like in this design?

Hierarchical Solution: Top-Down Functional Decomposition



Modules of **execute_session** and **execute_state** are general enough on their *control structures*. ⇒ *reusable*

Hierarchical Solution: System Control

All interactive sessions **share** the following *control pattern*:

- Start with some *initial state*.
- Repeatedly make *state transitions* (based on *choices* read from the user) until the state is *final* (i.e., the user wants to exit).

```
execute_session
    -- Execute a full interactive session.
  local
    current_state , choice: INTEGER
  do
    from
      current_state := initial
    until
      is_final (current_state)
    do
      choice := execute_state ( current_state )
      current_state := transition (current_state, choice)
    end
  end
```

Hierarchical Solution: State Handling (1)

The following *control pattern* handles **all** states:

```
execute_state ( current_state : INTEGER): INTEGER
    -- Handle interaction at the current state.
    -- Return user's exit choice.
  local
    answer: ANSWER; valid_answer: BOOLEAN; choice: INTEGER
  do
    from
    until
      valid_answer
    do
      display( current_state )
      answer := read_answer( current_state )
      choice := read_choice( current_state )
      valid_answer := correct( current_state , answer)
      if not valid_answer then message( current_state , answer)
    end
    process( current_state , answer)
    Result := choice
  end
```

Hierarchical Solution: State Handling (2)

FEATURE CALL	FUNCTIONALITY
`display`(**s**)	Display screen outputs associated with ***state*** *s*
`read_answer`(**s**)	Read user's input for answers associated with ***state*** *s*
`read_choice`(**s**)	Read user's input for exit choice associated with ***state*** *s*
`correct`(**s**, answer)	Is the user's *answer* valid w.r.t. ***state*** *s*?
`process`(**s**, answer)	Given that user's *answer* is valid w.r.t. ***state*** *s*, process it accordingly.
`message`(**s**, answer)	Given that user's *answer* is not valid w.r.t. ***state*** *s*, display an error message accordingly.

Q: How similar are the code structures of the above state-dependant commands or queries?

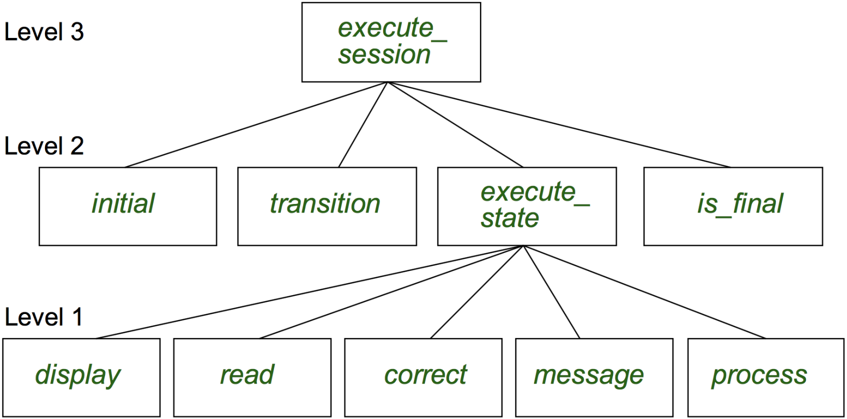
Hierarchical Solution: State Handling (3)

A: Actions of all such state-dependant features must **explicitly** *discriminate* on the input state argument.

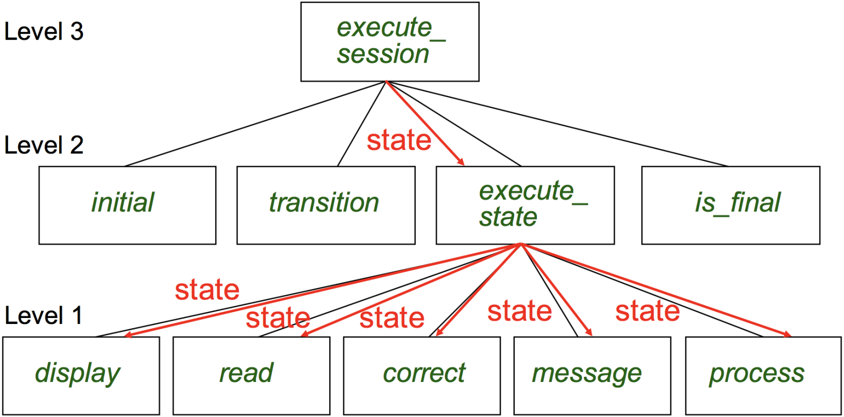
```
display(current_state: INTEGER)
  require
    valid_state: 1 ≤ current_state ≤ 6
  do
    if current_state = 1 then
      -- Display Initial Panel
    elseif current_state = 2 then
      -- Display Flight Enquiry Panel
    ...
    else
      -- Display Final Panel
    end
  end
```

- Such design ***smells***!
  ∵ Same list of conditional repeats for **all** state-dependant features.
- Such design ***violates*** the *Single Choice Principle*.
  e.g., To add/delete a state ⇒ Add/delete a branch in all such features.

Hierarchical Solution: Visible Architecture



Hierarchical Solution: Pervasive States



Too much data transmission: `current_state` is passed

- From `execute_session` (**Level 3**) to `execute_state` (**Level 2**)
- From `execute_state` (**Level 2**) to all features at **Level 1**

Law of Inversion

If your routines exchange too many data, then put your routines in your data.

e.g.,

`execute_state` (**Level 2**) and all features at **Level 1**:

- Pass around (as ***inputs***) the notion of ***current_state***
- Build upon (via ***discriminations***) the notion of ***current_state***

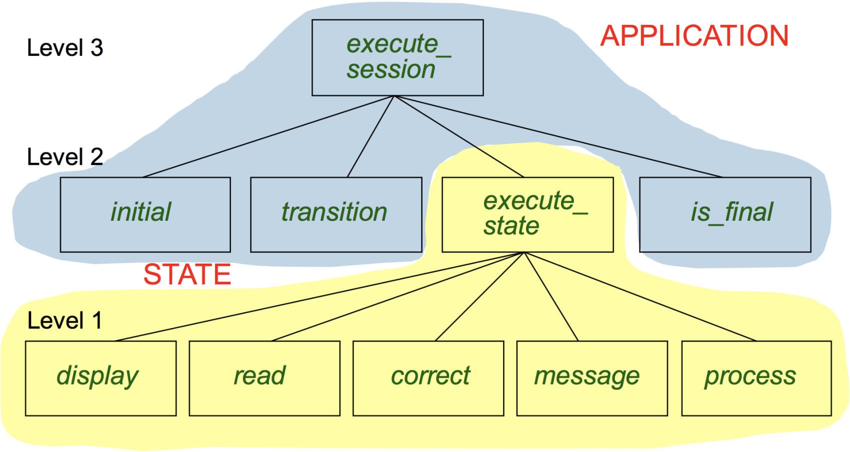
execute_state	(*s: INTEGER*)
display	(*s: INTEGER*)
read_answer	(*s: INTEGER*)
read_choice	(*s: INTEGER*)
correct	(*s: INTEGER* ; answer: ANSWER)
process	(*s: INTEGER* ; answer: ANSWER)
message	(*s: INTEGER* ; answer: ANSWER)

⇒ *Modularize* the notion of state as ***class STATE***.

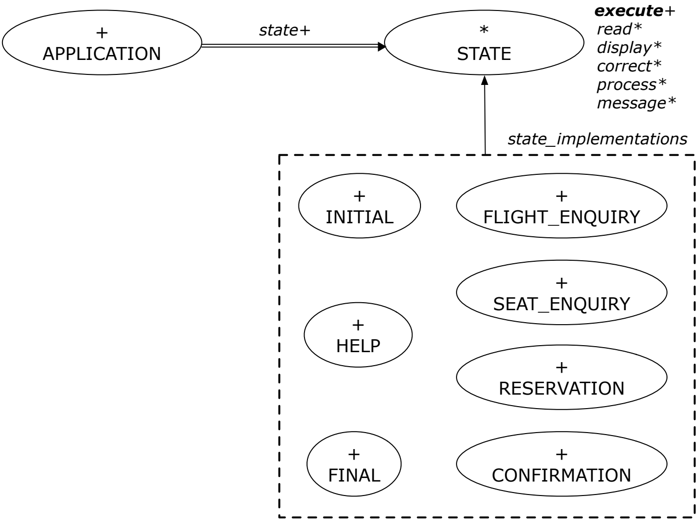
⇒ *Encapsulate* state-related information via a ***STATE*** interface.

⇒ Notion of ***current_state*** becomes ***implicit***: the `Current` class.

Grouping by Data Abstractions



Architecture of the State Pattern



The STATE ADT

```
deferred class STATE
  read
    -- Read user's inputs
    -- Set 'answer' and 'choice'
    deferred end
  answer: ANSWER
    -- Answer for current state
  choice: INTEGER
    -- Choice for next step
  display
    -- Display current state
    deferred end
  correct: BOOLEAN
    deferred end
  process
    require correct
    deferred end
  message
    require not correct
    deferred end
```

```
  execute
    local
      good: BOOLEAN
    do
      from
      until
        good
      loop
        display
        -- set answer and choice
        read
        good := correct
        if not good then
          message
        end
      end
      process
  end
end
```

The Template Design Pattern

Consider the following fragment of Eiffel code:

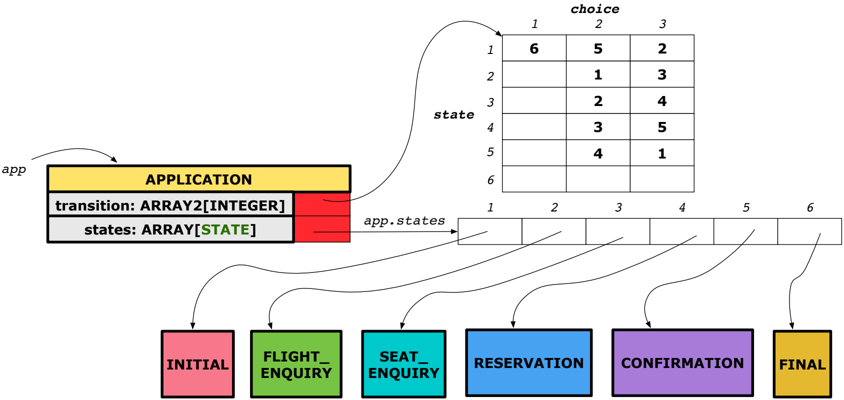
```
1 s: STATE
2 create {SEAT_ENQUIRY} s.make
3 s.execute
4 create {CONFIRMATION} s.make
5 s.execute
```

L2 and **L4**: the same version of effective feature `execute` (from the deferred class ***STATE***) is called. [*template*]

L2: specific version of effective features `display`, `process`, *etc.*, (from the effective descendant class ***SEAT_ENQUIRY***) is called. [*template instantiated for* ***SEAT_ENQUIRY***]

L4: specific version of effective features `display`, `process`, *etc.*, (from the effective descendant class ***CONFIRMATION***) is called. [*template instantiated for* ***CONFIRMATION***]

APPLICATION Class: Array of STATE



APPLICATION Class (1)

```
class APPLICATION create make
feature {NONE} -- Implementation of Transition Graph
  transition: ARRAY2[INTEGER]
    -- State transitions: transition[state, choice]
  states: ARRAY[STATE]
    -- State for each index, constrained by size of 'transition'
feature
  initial: INTEGER
  number_of_states: INTEGER
  number_of_choices: INTEGER
  make(n, m: INTEGER)
    do number_of_states := n
       number_of_choices := m
       create transition.make_filled(0, n, m)
       create states.make_empty
    end
invariant
  transition.height = number_of_states
  transition.width = number_of_choices
end
```

APPLICATION Class (2)

```
class APPLICATION
feature {NONE} -- Implementation of Transition Graph
  transition: ARRAY2[INTEGER]
  states: ARRAY[STATE]
feature
  put_state(s: STATE; index: INTEGER)
    require 1 ≤ index ≤ number_of_states
    do states.force(s, index) end
  choose_initial(index: INTEGER)
    require 1 ≤ index ≤ number_of_states
    do initial := index end
  put_transition(tar, src, choice: INTEGER)
    require
      1 ≤ src ≤ number_of_states
      1 ≤ tar ≤ number_of_states
      1 ≤ choice ≤ number_of_choices
    do
      transition.put(tar, src, choice)
    end
end
```

Example Test: Non-Interactive Session

```
test_application: BOOLEAN
  local
    app: APPLICATION ; current_state: STATE ; index: INTEGER
  do
    create app.make (6, 3)
    app.put_state (create {INITIAL}.make, 1)
    -- Similarly for other 5 states.
    app.choose_initial (1)
    -- Transit to FINAL given current state INITIAL and choice 1.
    app.put_transition (6, 1, 1)
    -- Similarly for other 10 transitions.

    index := app.initial
    current_state := app.states [index]
    Result := attached {INITIAL} current_state
    check Result end
    -- Say user's choice is 3: transit from INITIAL to FLIGHT_STATUS
    index := app.transition.item (index, 3)
    current_state := app.states [index]
    Result := attached {FLIGHT_ENQUIRY} current_state
end
```

APPLICATION Class (3): Interactive Session

```
class APPLICATION
feature {NONE} -- Implementation of Transition Graph
  transition: ARRAY2[INTEGER]
  states: ARRAY[STATE]
feature
  execute_session
    local
      current_state: STATE
      index: INTEGER
    do
      from
        index := initial
      until
        is_final (index)
      loop
        current_state := states[index]  -- polymorphism
        current_state.execute  -- dynamic binding
        index := transition.item (index, current_state.choice)
      end
    end
end
```

Building an Application

- Create instances of STATE.

```
s1: STATE
create {INITIAL} s1.make
```

- Initialize an APPLICATION.

```
create app.make(number_of_states, number_of_choices)
```

- Perform polymorphic assignments on app.states.

```
app.put_state(initial, 1)
```

- Choose an initial state.

```
app.choose_initial(1)
```

- Build the transition table.

```
app.put_transition(6, 1, 1)
```

- Run the application.

```
app.execute_session
```

Top-Down, Hierarchical vs. OO Solutions

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- In the second (top-down, hierarchy) solution, it is required for every state-related feature to *explicitly* and *manually* discriminate on the argument value, via a a list of conditionals.

  e.g., Given `display(current_state: INTEGER)`, the calls `display(1)` and `display(2)` behave differently.

- The third (OO) solution, called the State Pattern, makes such conditional *implicit* and *automatic*, by making `STATE` as a deferred class (whose descendants represent all types of states), and by delegating such conditional actions to *dynamic binding*.

  e.g., Given `s: STATE`, behaviour of the call `s.display` depends on the *dynamic type* of `s` (such as `INITIAL` vs. `FLIGHT_ENQUIRY`).

Index (1)

Index (2)

Index (3)