# The State Design Pattern

**Readings: OOSC2 Chapter 20**

EECS3311 A & E: Software Design
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# Learning Objectives

Upon completing this lecture, you are expected to understand:

**1.** Motivating Problem: *Interactive* Systems

**2.** First Design Attempt: Assembly Style

**3.** Second Design Attempt: *Hierarchical*, Procedural Sylte

**4.** `Template` & `State` Design Patterns: OO, *Polymorphic*

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* :
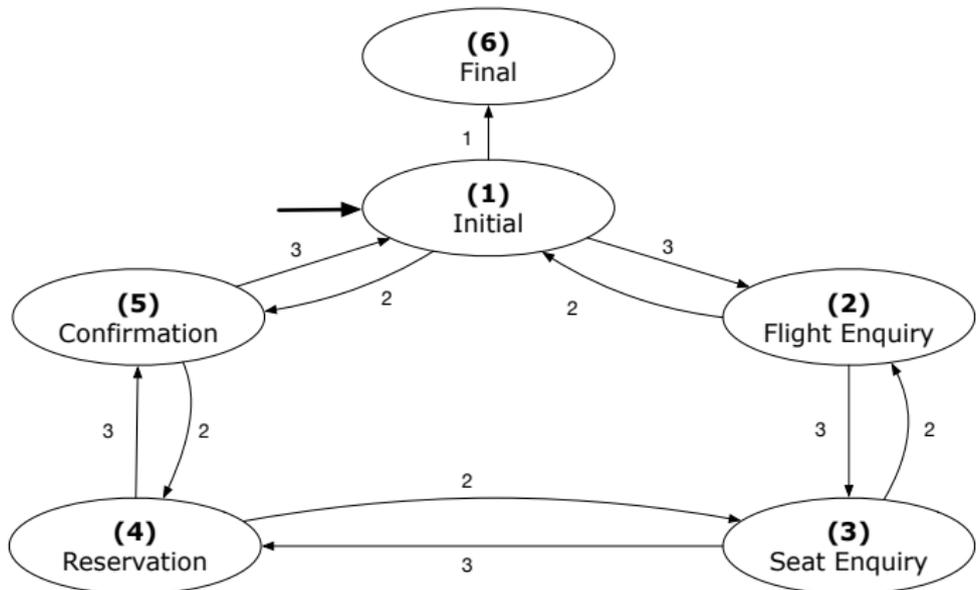
# Design Challenges

**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.

```
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.

| CHOICE SRC STATE | 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) | – | – | – |

| state | *choice* 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

Level 3

```
execute_
session
```

Level 2

| initial | transition | execute_state | is_final |

Level 1

| display | read | correct | message | process |
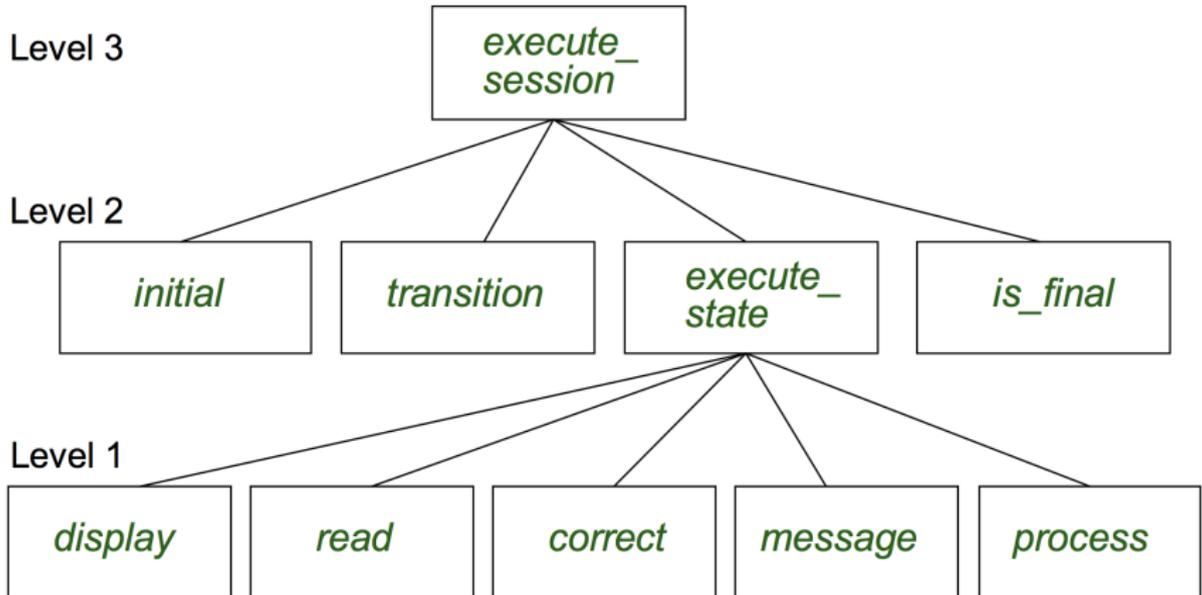
Modules of **execute_session** and **execute_state** are general
enough on their *control structures*.          $\Rightarrow$  *reusable*

## 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
```

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
```

| 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?

**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



Level 3 — execute_session

Level 2 — initial, transition, execute_state, is_final

Level 1 — display, read, correct, message, process
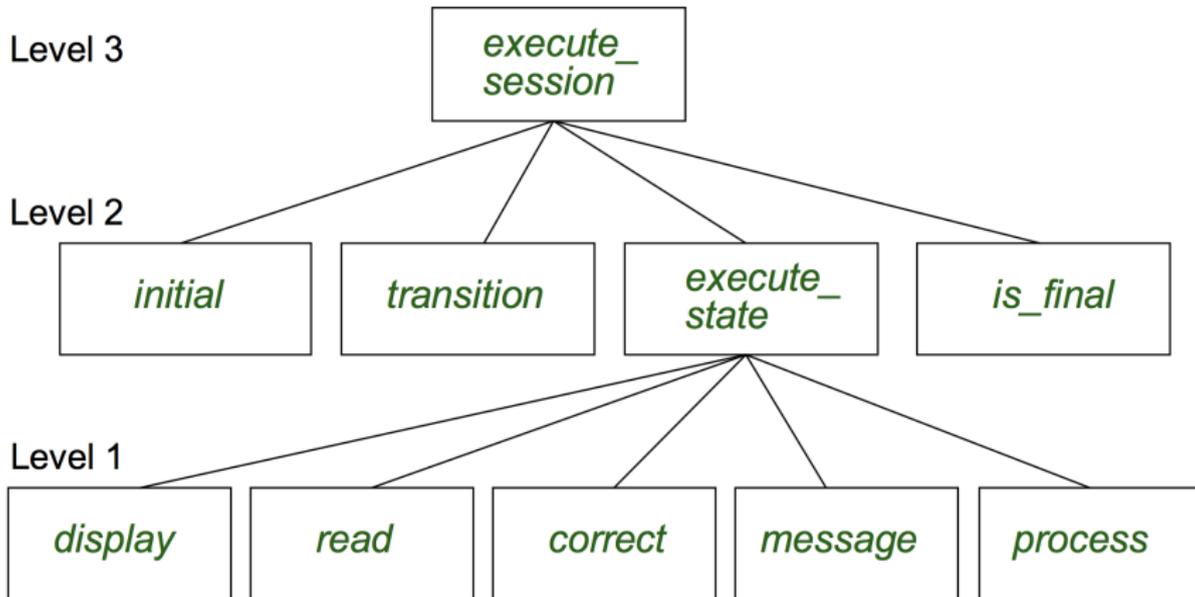
# Hierarchical Solution: Pervasive States
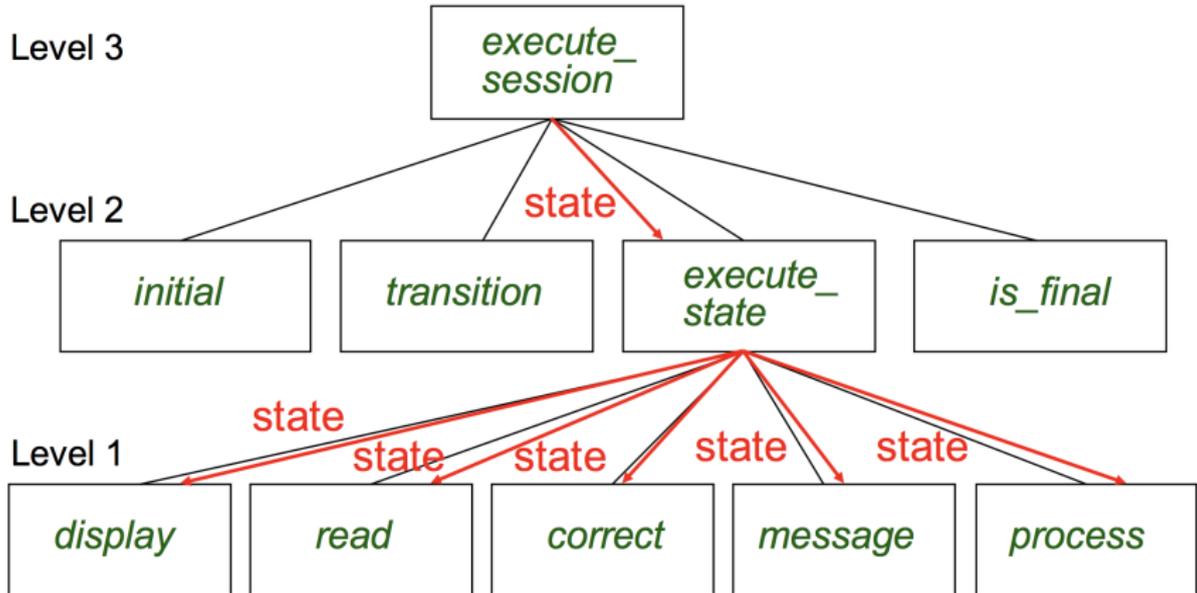


Too much data transmission: `current_state` is passed
- From `execute_session` (**Level 3**) to `execute_state` (**Level 2**)
- From `execute_state` (**Level 2**) to all features at **Level 1**

# 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.
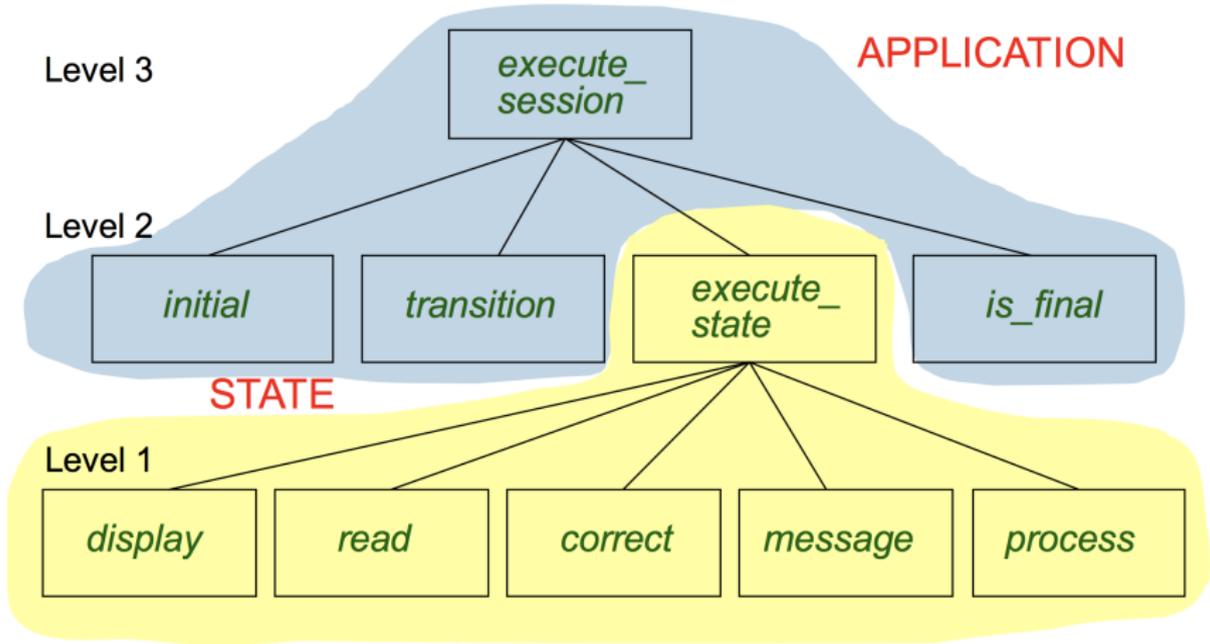
# Architecture of the State Pattern
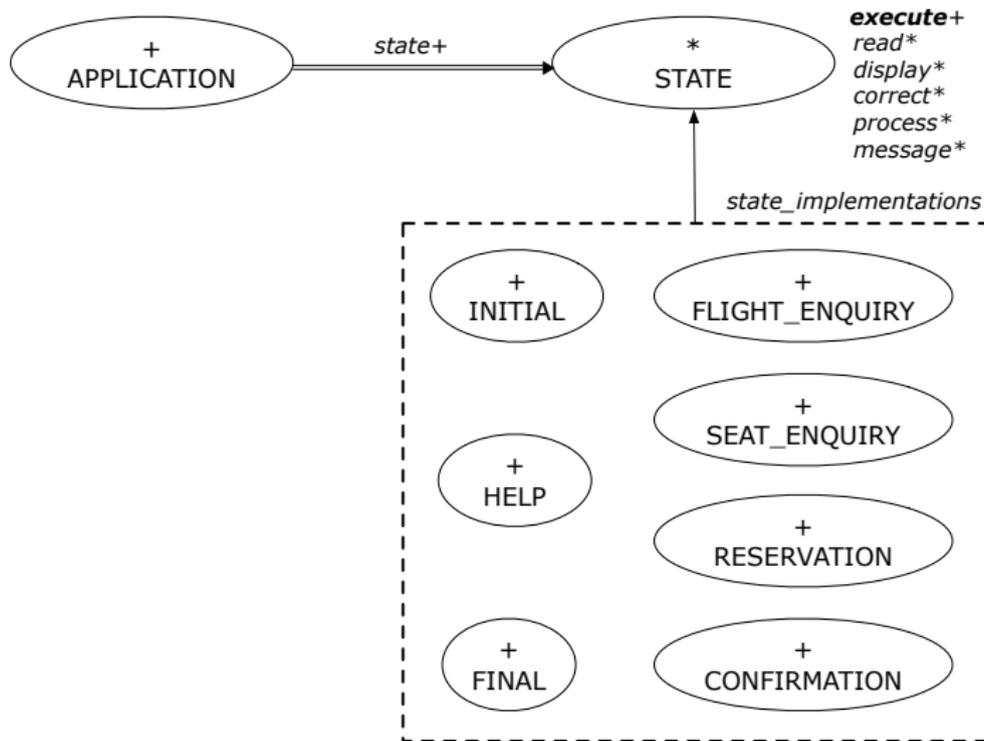
## The STATE ADT

```
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** ]
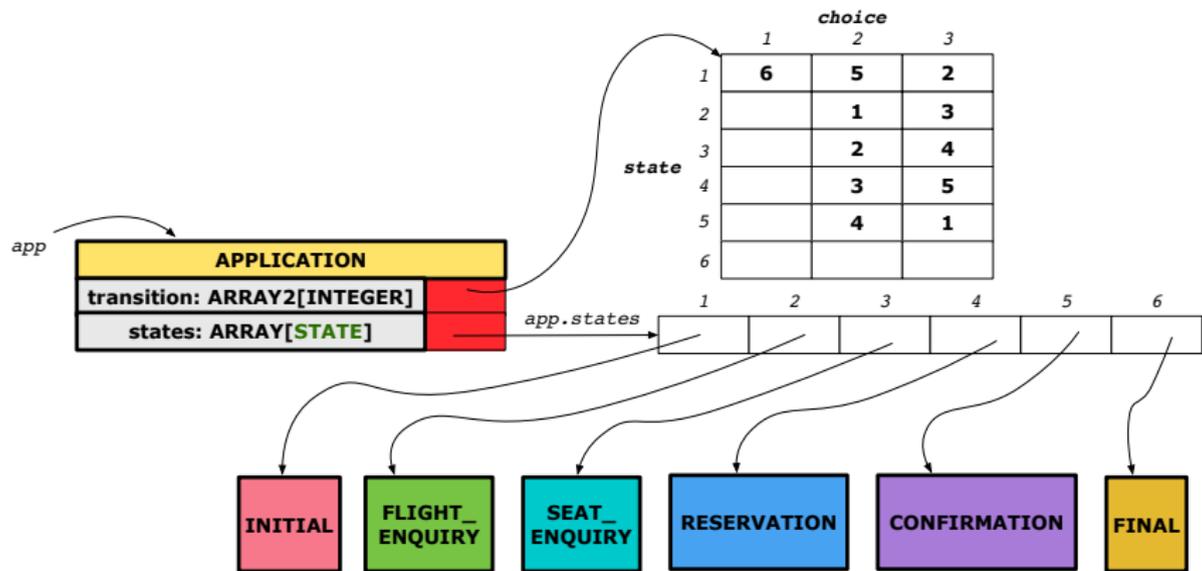
```
class APPLICATION create make
feature {TEST_APPLICATION} -- Implementation of Transition Graph
  transition: ARRAY2[INTEGER]
    -- State transitions: transition[state, choice]
  states: ARRAY[STATE]
    -- State for each index, constrained by size of 'transition'
feature
  initial: INTEGER
  number_of_states: 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
```

```
class APPLICATION
feature {TEST_APPLICATION} -- 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
```

```
class APPLICATION
feature {TEST_APPLICATION} -- 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
```

- 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(create {INITIAL}.make, 4)
```

- 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

- 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)**

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