An O-O design example
A reservation panel

-- Enquiry on Flights --

Flight sought from: Santa Barbara           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
The transition diagram

![Transition Diagram]

1. Help → Initial: 1
2. Initial → Help: 1
3. Help → Enquiry_on_flights: 2
4. Enquiry_on_flights → Help: 2
5. Initial → Enquiry_on_flights: 3
6. Enquiry_on_flights → Initial: 2
7. Initial → Reservation: 3
8. Reservation → Initial: 3
9. Help → Reservation: 1
10. Reservation → Help: 1
11. Enquiry_on_seats → Help: 1
12. Help → Enquiry_on_seats: 1

States:
- Help
- Initial
- Confirmation
- Reservation
- Enquiry_on_flights
- Enquiry_on_seats
A first attempt

```
PEnquiry_on_flights:
    output "enquiry on flights" screen
    repeat
        read user's answers and his exit choice C
        if error in answer then
            output message
        end
    until no error in answer
end

process answer
inspect C
    when C0 then
        goto Exit
    when C1 then
        goto PHelp
    ...
    when Cm-1 then
        goto PReservation
end
... (and similarly for each state)
```
What’s wrong with the previous scheme?

- Intricate branching structure ("spaghetti bowl").
- Extendibility problems: dialogue structure wired into program structure.
A functional, top-down solution

For more flexibility, represent the structure of the transition diagram by a function

\[ \text{transition}(i, k) \]

used to specify the transition diagram associated with any particular interactive application.

Function \text{transition} may be implemented as a data structure, for example a two-dimensional array.
The transition function

<table>
<thead>
<tr>
<th></th>
<th>0 (Initial)</th>
<th>1 (Help)</th>
<th>2 (Conf.)</th>
<th>3 (Reserv.)</th>
<th>4 (Seats)</th>
<th>5 (flights)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (Initial)</td>
<td></td>
<td></td>
<td>2</td>
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<tr>
<td>1 (Help)</td>
<td>Exit</td>
<td>return</td>
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<td>2 (Conf.)</td>
<td>Exit</td>
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<td>3</td>
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<tr>
<td>5 (flights)</td>
<td>Exit</td>
<td></td>
<td>0</td>
<td>4</td>
<td></td>
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</tbody>
</table>
The transition diagram
New system architecture

Level 3
- execute_session

Level 2
- initial
- transition
- execute_state
- is_final

Level 1
- display
- read
- correct
- message
- process
New system architecture

Procedure `execute_session` only defines graph traversal.

Knows nothing about particular screens of a given application. Should be the same for all applications.

```plaintext
execute_session is
   -- Execute full session
   local
   current_state, choice: INTEGER
   do
      current_state := initial
      repeat
         choice := execute_state (current_state)
         current_state := transition (current_state, choice)
      until is_final (current_state)
   end
end
```
To describe an application

- Provide *transition* function
- Define *initial* state
- Define *is_final* function
Actions in a state

\textbf{execute\_state}\( (\text{current\_state}: \text{INTEGER})\): \text{INTEGER} \text{ is}

\begin{itemize}
\item \text{local}
\begin{itemize}
\item \text{answer}: \text{ANSWER}
\item \text{good}: \text{BOOLEAN}
\item \text{choice}: \text{INTEGER}
\end{itemize}
\end{itemize}

\begin{itemize}
\item \text{do}
\item \text{repeat}
\begin{itemize}
\item \text{display}\( (\text{current\_state})\)
\item \text{[answer, choice]} := \text{read}\( (\text{current\_state})\)
\item \text{good} := \text{correct}\( (\text{current\_state, answer})\)
\item \text{if not good then}
\item \text{message}\( (\text{current\_state, answer})\)
\item \text{end}
\end{itemize}
\item \text{until}
\item \text{good}
\item \text{end}
\end{itemize}

\text{process}\( (\text{current\_state, answer})\)

\text{return}
\text{choice}

\text{end}
Specification of the remaining routines

- **display** \( (s) \) outputs the screen associated with state \( s \).
- \( [a, e] := \text{read} (s) \) reads into \( a \) the user’s answer to the display screen of state \( s \), and into \( e \) the user’s exit choice.
- **correct** \( (s, a) \) returns true if and only if \( a \) is a correct answer for the question asked in state \( s \).
- If so, **process** \( (s, a) \) processes answer \( a \).
- If not, **message** \( (s, a) \) outputs the relevant error message.
Going object-oriented: The law of inversion

How amenable is this solution to change and adaptation?

- New transition?
- New state?
- New application?

Routine signatures:

- `execute_state` (state: INTEGER): INTEGER
- `display` (state: INTEGER)
- `read` (state: INTEGER): [ANSWER, INTEGER]
- `correct` (state: INTEGER, a: ANSWER): BOOLEAN
- `message` (state: INTEGER, a: ANSWER)
- `process` (state: INTEGER, a: ANSWER)
- `is_final` (state: INTEGER)
Going object-oriented: The law of inversion

How amenable is this solution to change and adaptation?

- New transition?
- New state?
- New application?

Routine signatures:

- `execute_state (state: INTEGER): INTEGER`
- `display (state: INTEGER)`
- `read (state: INTEGER): [ANSWER, INTEGER]`
- `correct (state: INTEGER; a: ANSWER): BOOLEAN`
- `message (state: INTEGER; a: ANSWER)`
- `process (state: INTEGER; a: ANSWER)`
- `is_final (state: INTEGER)`
Data transmission

All routines share the state as input argument. They must discriminate on that argument, e.g.:

```pascal
display (current_state: INTEGER) is
  do
    inspect current_state
    when state1 then ...
    when state2 then ...
    when staten then ...
  end
end
```

Consequences:
- Long and complicated routines.
- Must know about one possibly complex application.
- To change one transition, or add a state, need to change all.
The flow of control

Underlying reason why structure is so inflexible:

Too much DATA TRANSMISSION.

Variable `current_state` is passed from `execute_session` (level 3) to all routines on level 2 and on to level 1.

Worse: there’s another implicit argument to all routines - application. Can’t define `execute_session, display, execute_state, ...`

as library components, since each must know about all interactive applications that may use it.
The visible architecture

Level 3

execute_session

Level 2

initial
transition
execute_state
is_final

Level 1

display
read
correct
message
process
The real story

Level 3

execute_session

Level 2

initial
transition
execute_state
is_final

Level 1

display
read
correct
message
process

state
state
state
state
state
The law of inversion

The everywhere lurking state

- If your routines exchange data too much, put your routines into your data.
Going O-O

Use **STATE** as the basic **abstract data type** (yielding a class).

Among features of a state:

- The routines of level 1
  (deferred in **STATE**)

- **execute_state**, as above but without **current_state** argument.
Grouping by data abstractions

Level 3

execute_session

Level 2

initial
transition
execute_state
is_final

STATE

Level 1

display
read
correct
message
process
Class \textit{STATE}

defered class \textit{STATE}

\textbf{feature}\

\begin{itemize}
\item \textit{choice} : \textbf{INTEGER} \\
   -- User's selection for next step
\item \textit{input} : \textbf{ANSWER} \\
   -- User's answer for this step
\end{itemize}

display is \\

\begin{itemize}
\item deferred 
\item end
\end{itemize}

read is \\

\begin{itemize}
\item deferred 
\item ensure 
\item \textit{input} \neq \textbf{Void}
\item end
\end{itemize}

correct. \textbf{BOOLEAN} is \\

\begin{itemize}
\item deferred 
\item end
\end{itemize}
Class \textit{STATE}

\textit{message} is
\begin{itemize}
  \item \textit{require not correct}
  \item \textit{deferred}
\end{itemize}
\textit{end}

\textit{process} is
\begin{itemize}
  \item \textit{require correct}
  \item \textit{deferred}
\end{itemize}
\textit{end
Class \textit{STATE}

\begin{verbatim}
execute_state is
  local
    good: BOOLEAN
  do
    from until good
      loop
        display read
        good := correct
        if not good then
          message
        end
      end
    end
  end
process
  choice := input.choice
end
\end{verbatim}
Class structure

STATE

INITIAL  RESERVATION  CONFIRMATION
To describe a state of an application

Introduce new descendant of \textit{STATE}:


class \textit{ENQUIRY\_ON\_FLIGHTS} inherit \textit{STATE} feature

\textit{display} is do ... end
\textit{read} is do ... end
\textit{correct: BOOLEAN} is do ... end
\textit{message} is do ... end
\textit{process} is do ... end

end
Rearranging the modules

APPLICATION

Level 3

execute_session

Level 2

initial
transition
execute_state
is_final

STATE

Level 1

display
read
correct
message
process
Describing a complete application

No "main program" but class representing a system.

Describe application by remaining features at levels 1 and 2:

- Function `transition`.
- State `initial`.
- Boolean function `is_final`.
- Procedure `execute_session`.
Implementation decisions

- Represent transition by an array $transition$: n rows (number of states), m columns (number of choices), given at creation.

- States numbered from 1 to n; array $states$ yields the state associated with each index.
  (Reverse not needed: why?)

- No deferred boolean function $is_final$, but convention: a transition to state 0 denotes termination.

- No such convention for initial state (too constraining).
  Attribute $initial_number$. 
Describing an application

class APPLICATION
create
make
feature

initial: INTEGER

make (n, m: INTEGER) is

- Allocate with n states and m possible choices.
  do
  create transition.make (1, n, 1, m)
  create states.make (1, n)
end

feature {NONE} -- Representation of transition diagram

transition: ARRAY2[STATE]
- State transitions

states: ARRAY[STATE]
- State for each index
Array of states: A polymorphic container

\[ \textit{states: ARRAY [STATE]} \]

Notations for accessing array element, i.e. \textit{states[i]} in Pascal:

- \textit{states.item(i)}
- \textit{states @ i}

\textit{(Soon in Eiffel: just states[i])}
The array of states

STATES

(ENQUIRY_ON_FLIGHTS)

(ENQUIRY_ON_SEATS)

(INITIAL)

(CONFIRMATION)

(RESERVATION)
Executing a session

execute_session is
   -- Run one session of application
   local
      current_state: STATE    -- Polymorphic!
      index: INTEGER
   do
      from
         index := initial
      invariant
         0 <= index
         index <= n
      until
         index = 0
      loop
         current_state := states @ index
         current_state.execute_state
         check
         1 <= current_state.choice
         current_state.choice <= m
      end
      index := transition.item (index, current_state.choice)
   end
Class structure

* STATE

INITIAL

RESERVATION

CONFIRMATION

...
Other features of \textit{APPLICATION}

\begin{verbatim}
put_state (s: STATE, number: INTEGER) is
    -- Enter state s with index number.
    require 1 <= number
    number <= states.upper
    do
        states.put (number, s)
    end

choose_initial (number: INTEGER) is
    -- Define state number \textit{number} as the initial
    -- state.
    require 1 <= number
    number <= states.upper
    do
        first_number := number
    end
\end{verbatim}
More features of **APPLICATION**

```plaintext
put_transition (source, target, label: INTEGER) is
   -- Add transition labeled label from state
   -- number source to state number target. require
   1 <= source
   source <= states.upper
   0 <= target
   target <= states.upper
   1 <= label
   label <= transition.upper2
   do
      transition.put (source, label, target)
   end

invariant
   0 <= st_number
   st_number <= n
   transition.upper1 = states.upper

end
```

Programming in the Large, 2004
To build an application

Necessary states — instances of \textit{STATE} — should be available.

Initialize application:

\begin{itemize}
  \item \textbf{create} \texttt{a.make} (\texttt{state\_count}, \texttt{choice\_count})
  \item Assign a number to every relevant state \textit{s}:
    \texttt{a.put\_state} (\textit{s}, \textit{n})
  \item Choose initial state \textit{n₀}:
    \texttt{a.choose\_initial} (\textit{n₀})
  \item Enter transitions:
    \texttt{a.put\_transition} (\texttt{sou}, \texttt{tar}, \texttt{lab})
  \item May now run:
    \texttt{a.execute\_session}
\end{itemize}
Open architecture

During system evolution you may at any time:

- Add a new transition (*put_transition*).
- Add a new state (*put_state*).
- Delete a state (not shown, but easy to add).
- Change the actions performed in a given state.
- ...
Note on the architecture

Procedure `execute_session` is not "the function of the system" but just one routine of `APPLICATION`.

Other uses of an application:
- Build and modify: add or delete state, transition, etc.
- Simulate, e.g. in batch (replaying a previous session’s script), or on a line-oriented terminal.
- Collect statistics, a log, a script of an execution.
- Store into a file or data base, and retrieve.

Each such extension only requires incremental addition of routines. Doesn’t affect structure of `APPLICATION` and clients.
The system is open

Key to openness: architecture based on types of the problem’s objects (state, transition graph, application).

Basing it on “the” apparent purpose of the system would have closed it for evolution.

Real systems have no top
Object-Oriented Design

It’s all about finding the right data abstractions
End of lecture 19