Last update: 20 March 2007

Software Architecture

Bertrand Meyer

ETH Zurich, March-July 2007

Lecture 1: Introduction

Goal of the course

Introduce you to the techniques of building large software systems of high quality, in particular:

- Reliability
- Extendibility
- Reusability

This includes in particular:

- Principles of software quality
- Object technology principles and methods; the practice of object-oriented analysis, design and implementation
- Design patterns
- Principles of building reusable software
- Some key techniques of concurrent programming

Six key topics

- Modularity and reusability
- Abstract Data Types
- Design by Contract and other O-O principles
- Design Patterns
- Component-Based Development
- Introduction to concurrency

Practical information

Course material

Course page:

http://se.inf.ethz.ch/teaching/ss2007/0050/

→ Check it at least twice a week

Lecture material:

- Lecture slides
- Textbook:

  Object-Oriented Software Construction,
  2nd edition -- Prentice Hall, 1997

  Available from Polybuchhandlung (≈ CHF 63 with Legi)

Exercise material:

- Exercise sheets
- Master solutions

Electronic forums

Discussion forums:
Inforum:

http://forum.vis.ethz.ch

Mailing list for each group

Usual advice and rules:

- Use the forums and mailing lists! Take advantage of every help you can get.
- Don't be shy. There are no stupid questions.
- Criticism welcome, but always be polite to every participant and observe the etiquette.
- To email the whole teaching team (professor and assistants):

soft-arch-assi@se.inf.ethz.ch

Exercise sessions and project

Make sure to attend all sessions

Exercise sheets will be distributed by your assistant during the exercise session

Do all exercises and the project

Start of semester

No exercise session this week

Next week: single-group exercise session led by Bernd Schoeller; room will be announced

Exercise groups will be formed next week

Project

Details to be given early April

You will have the choice between four topic categories:

- TRAFFIC extension or improvement
- Games using EiffelMedia
- Open project to be discussed with assistant
- EiffelStudio extension or improvement

All projects will be done in Eiffel

EiffelStudio download:

http://www.eiffel.com/downloads/

Open-source version available for Windows, Linux and MacOS

This is a software architecture project

Design quality is essential

Group project, must be managed properly

Configuration management

Documentation

Quality standards (analysis, design, implementation)

Should be useful ("*Eat your own dog food!*")

The public presentation

All projects will be demonstrated

The best projects will be selected for presentation

Exam: **end of semester**

Tuesday, 19 June 2007, 14-16 (normal class time)

2-hour exam

No material allowed

Covers all material in the semester

Teaching staff

Bertrand Meyer

E-mail: Bertrand.Meyer@inf.ethz.ch
Office: RZ J6
Secretary: Claudia Günthart, (01) 632 83 46

Exercise sessions

All groups have one session a week:

- Thursday, 15:00-16:00

The assistants

Martin Nordio (Coordinating Assistant)
English

Ilinca Ciupa
English

Michela Pedroni
German

Bernd Schoeller
German

Till Bay
German (French)

Jason (Yi) Wei
English

End lecture 1

Last update: 20 March 2007

Software Architecture

Bertrand Meyer

ETH Zurich, March-July 2007

Lecture 2: A basic architecture example

Our first pattern example

Multi-panel interactive systems

Plan of the rest of this lecture:

- Description of the problem: an example
- An unstructured solution
- A top-down, functional solution
- An object-oriented solution yielding a useful design pattern
- Analysis of the solution and its benefits

A reservation panel

Flight sought from: Santa Barbara To: Zurich

Depart no earlier than: 18 Mar 2006 No later than: 18 Mar 2006

ERROR: Choose a date in the future

Choose next action:

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

A reservation panel

Flight sought from: Santa Barbara To: Zurich

Depart no earlier than: 18 Mar 2006 No later than: 18 Mar 2006

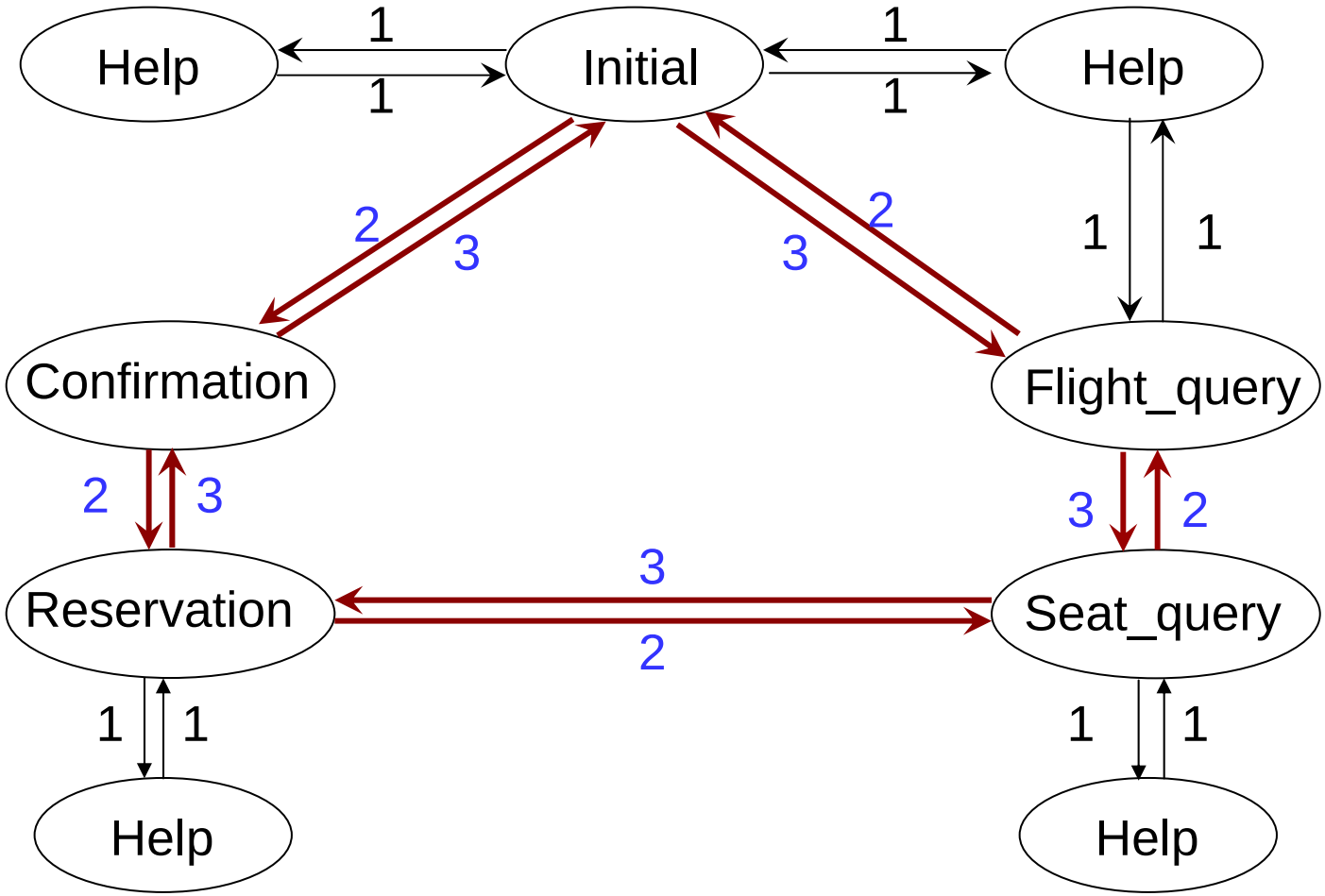
AVAILABLE FLIGHTS: 2

Flt# LH 425	Dep 8:25	Arr 7:45	Thru: Shanghai
Flt# CP 082	Dep 7:40	Arr 9:15	Thru: Hong Kong

Choose next action:

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

The transition diagram



A first attempt

A program block for each state, for example:

P_{Flight_query}:

```
display "enquiry on flights" screen
repeat
        Read user's answers and his exit choice C
        if Error_in_answer then output_message end
until
        not Error_in_answer
end

process answer

inspect C
        when 0 then goto P_Exit
        when 1 then goto P_Help
        ...
        when n then goto P_Reservation
end
```

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

Represent the structure of the diagram by a function

transition (*i*, *k*)

giving the state to go to from state *i* for choice *k*.

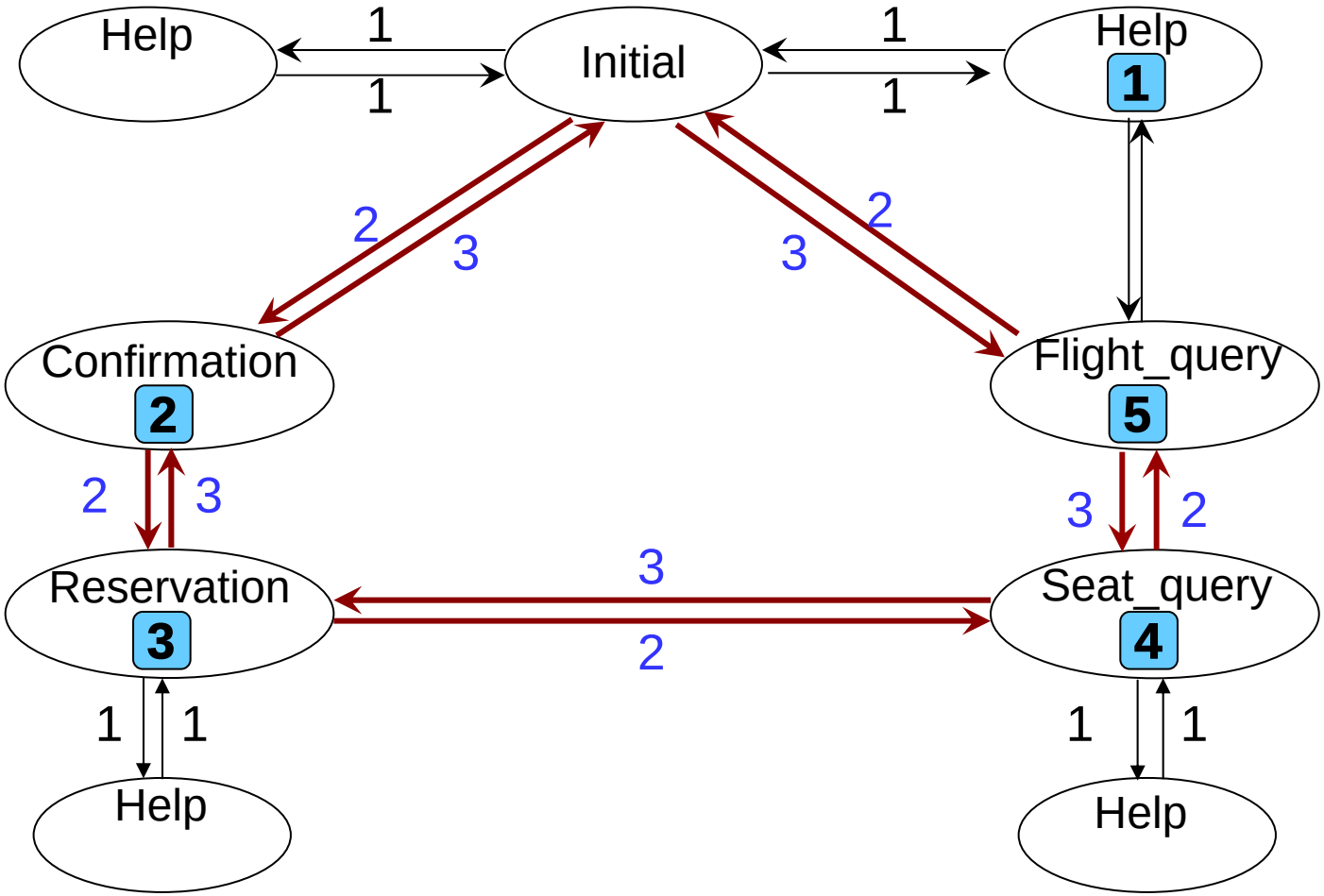
This describes the transitions of any particular application.

Function *transition* may be implemented as a data structure, for example a two-dimensional array.

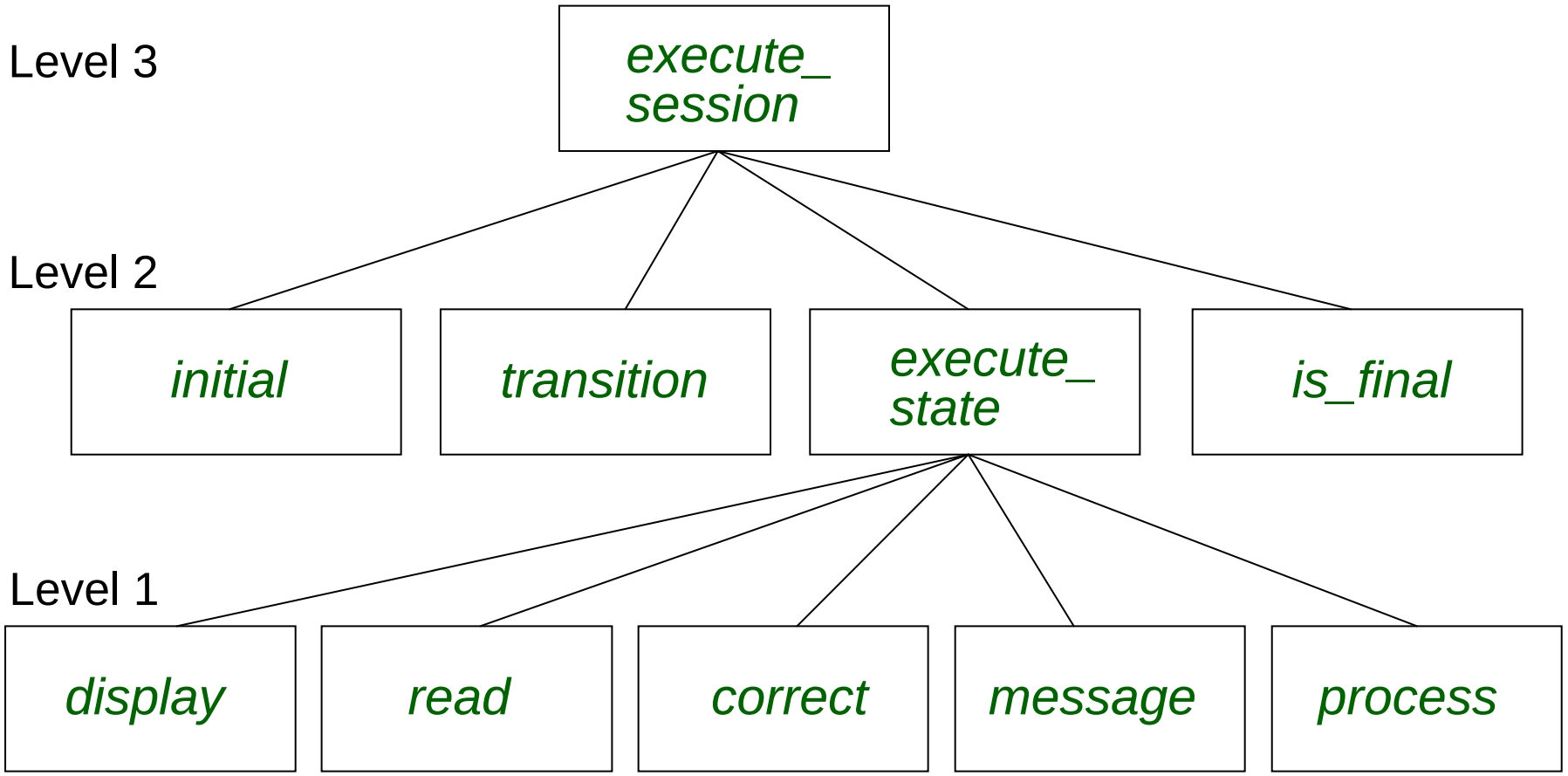
The transition function

	0	1	2	3
0 (Initial)			*2*	
1 (Help)	*Exit*	*Return*		
2 (Confirmation)	*Exit*		3	0
3 (Reservation)	*Exit*		4	2
4 (Seats)	*Exit*		5	3
5 (Flights)	*Exit*		0	4

The transition diagram



New system architecture



New system architecture

Procedure *execute_session* only defines graph traversal.

It knows nothing about particular screens of a given application;
it should be the same for all applications.

```
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

```
execute_state (current_state : INTEGER): INTEGER is
        -- Execute actions for current_state ; return user's exit choice.
local
        answer : ANSWER
        good : BOOLEAN
        choice : INTEGER
do
        repeat
                display (current_state)
                [answer, choice] := read (current_state)
                good := correct (current_state, answer)
                if not good then message (current_state, answer) end
        until
                good
        end
        process (current_state, answer)
return
        choice
end
```

Specification of the remaining routines

- *display* (*s*) outputs the screen associated with state *s*.
- [*a*, *e*] := *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)
```

Data transmission

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

```
display (current_state : INTEGER) is
        do
                inspect current_state
                        when state_1 then
                                ...
                        when state_2 then
                                ...
                        when state_n 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.

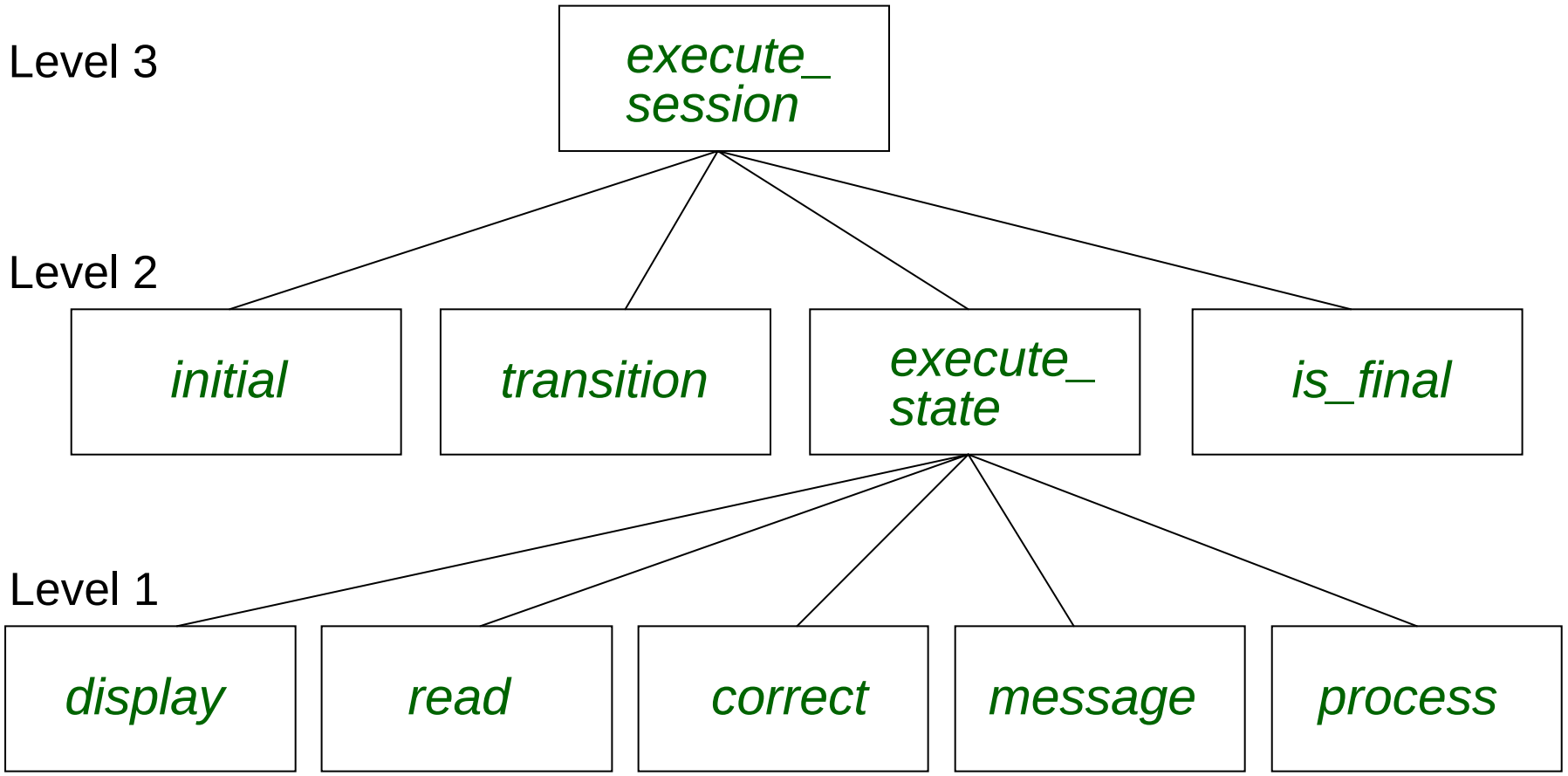
current_state is passed from *execute_session* (level 3) to all routines on level 2 and on to level 1

Worse: there's another implicit argument to all routines – application. Can't define

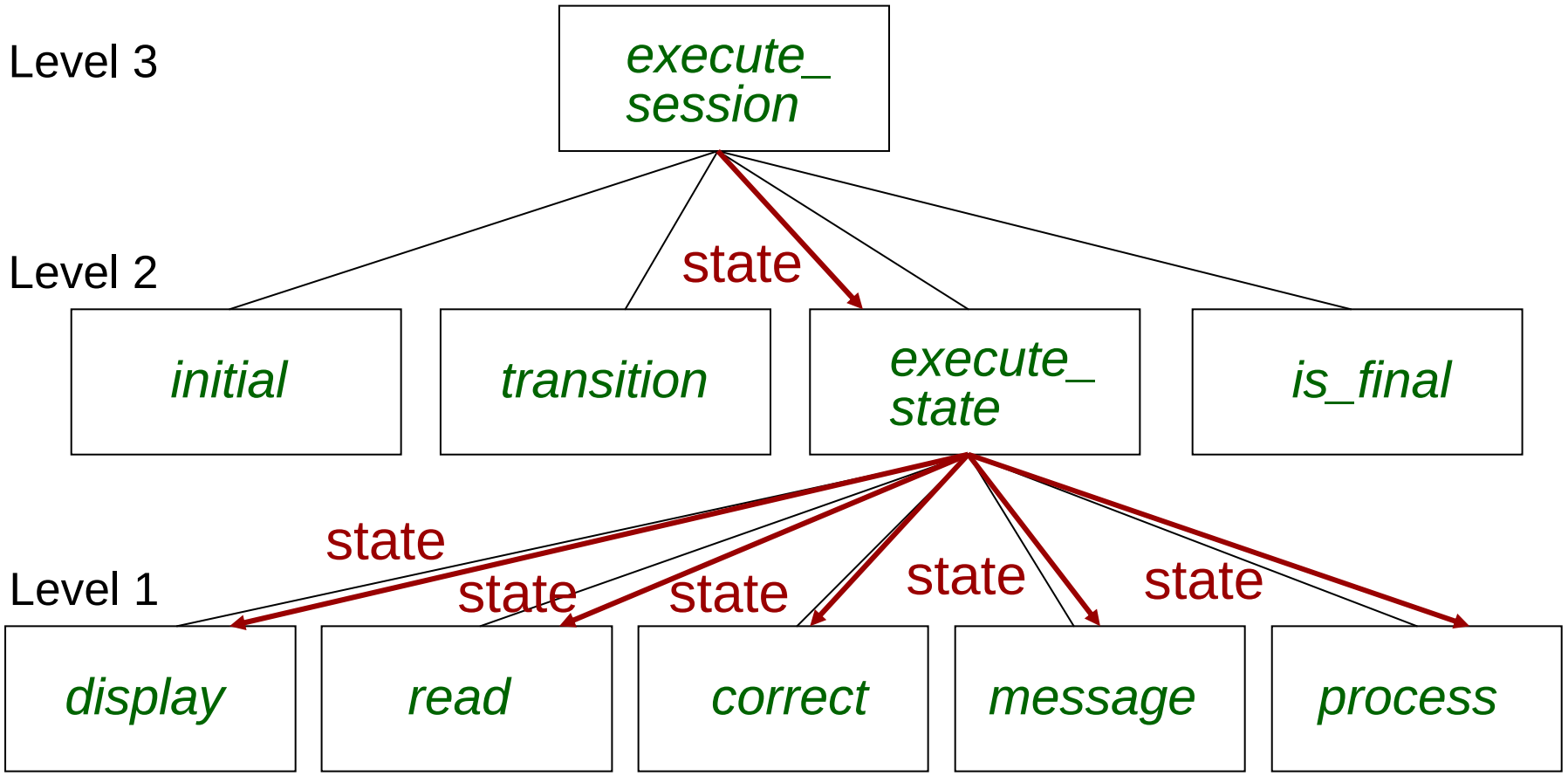
execute_session, *display*, *execute_state*, ...

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

The visible architecture



The real story



The law of inversion

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

In this example: the state is everywhere!

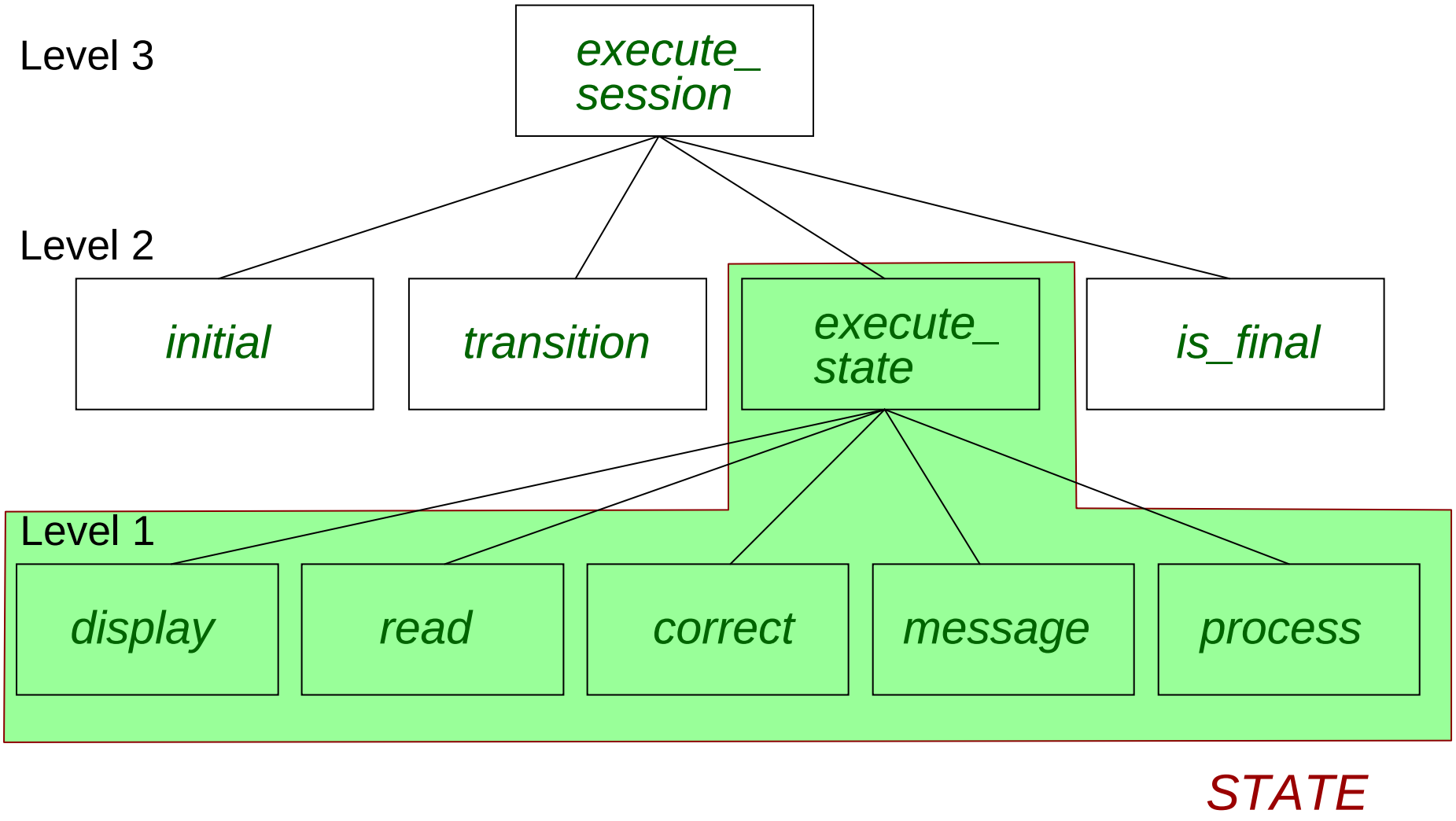
Going O-O

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

Among features of every state:

- The routines of level 1 (deferred in class *STATE*)
- *execute_state*, as above but without the argument *current_state*

Grouping by data abstractions



Class *STATE*

```
deferred class
    STATE
feature
    choice: INTEGER              -- User's selection for next step
    input: ANSWER                -- User's answer for this step
    display is
                    -- Show screen for this step.
        deferred
        end
    read is
                    -- Get user's answer and exit choice,
                    -- recording them into input and choice.
        deferred
        ensure
                    input /= Void
        end
```

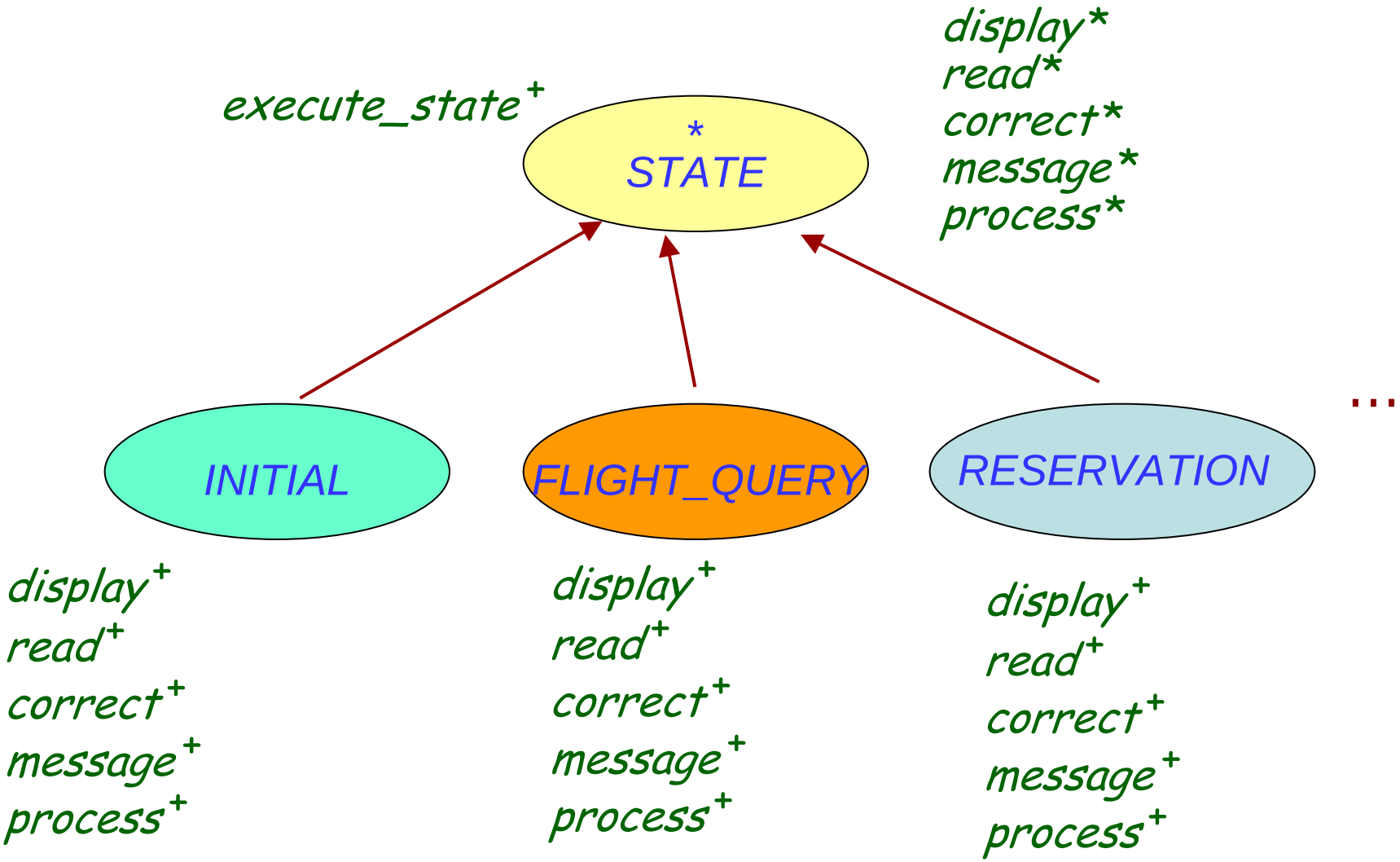
Class *STATE*

```
correct: BOOLEAN is
                -- Is input acceptable?
        deferred
        end

message is
                -- Display message for erroneous input.
        require
                not correct
        deferred
        end

process is
                -- Process correct input.
        require
                correct
        deferred
        end
```

Class *STATE*

```
    execute_state is
        local
                good: BOOLEAN
        do
                from
                until
                        good
                loop
                        display
                        read
                        good := correct
                        if not good then message end
                end
                process
                choice := input.choice
        end
end
```

Class structure

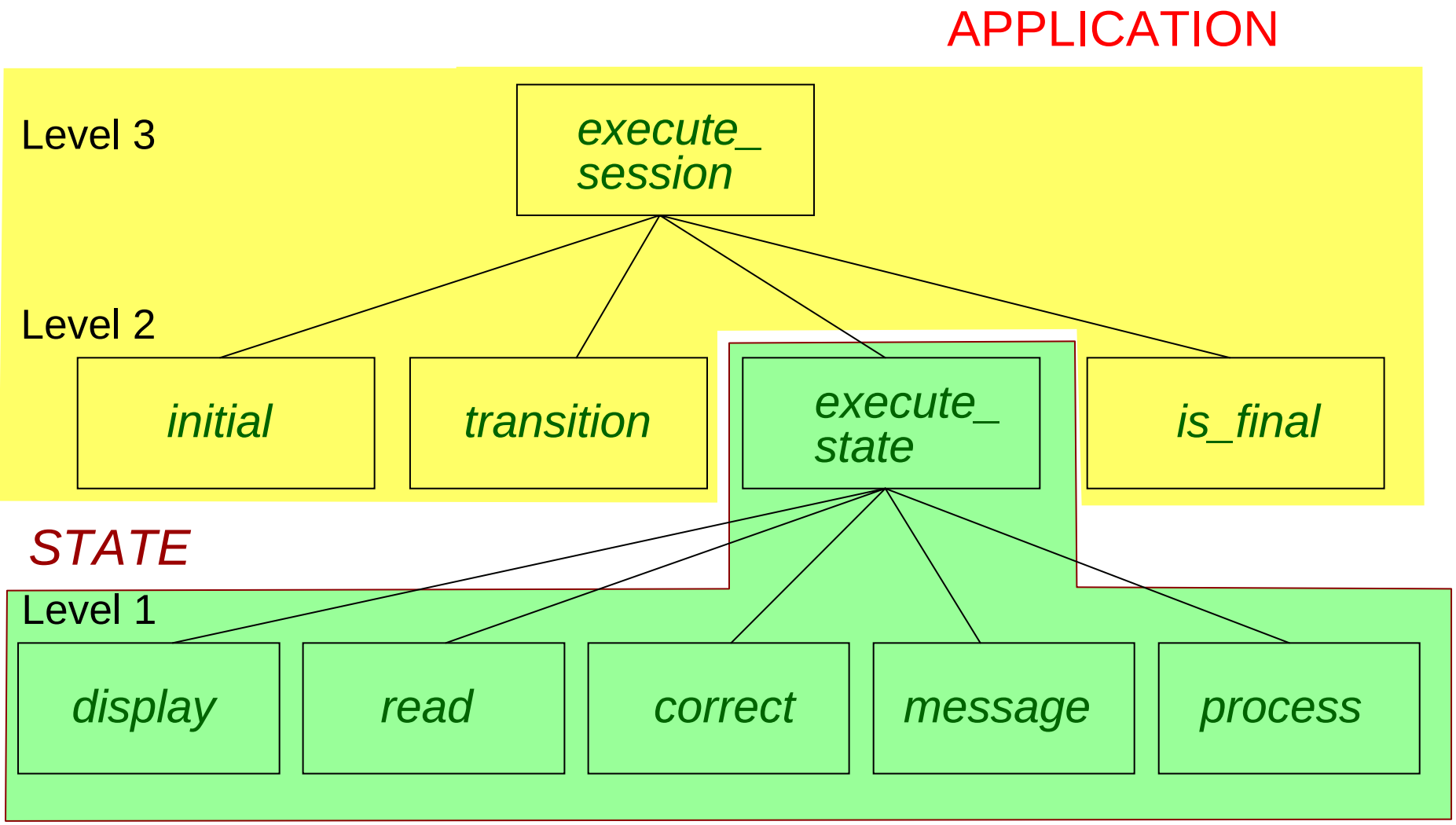


To describe a state of an application

Write a descendant of *STATE*:

```
class FLIGHT_QUERY inherit
        STATE
feature
        display is do ... end

        read is do ... end

        correct : BOOLEAN is do ... end

        message is do ... end

        process is do ... end
end
```

Rearranging the modules



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?)

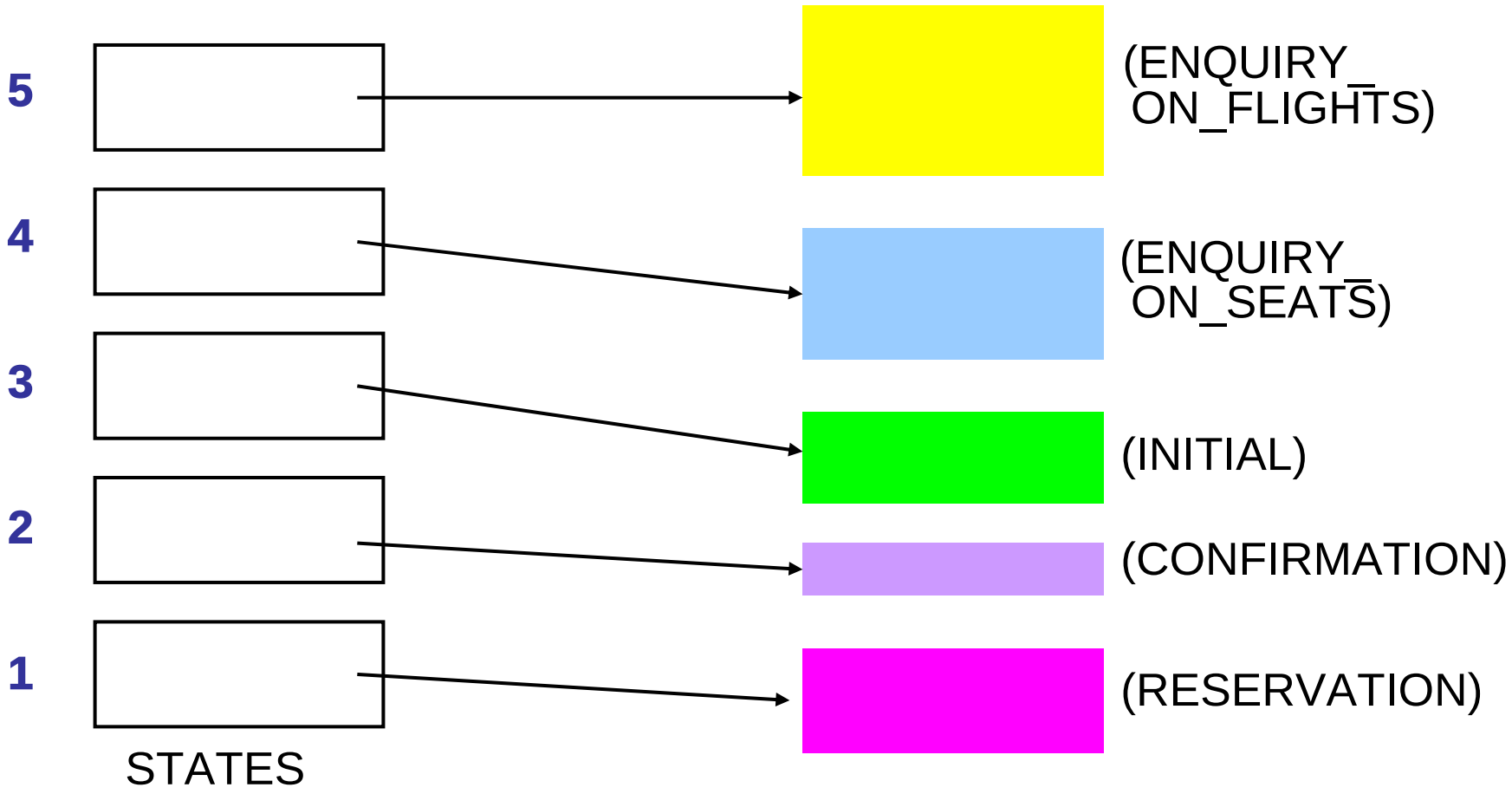
- No deferred boolean function *is_final*, but convention: a transition to state 0 denotes termination.

- 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
```

The array of states

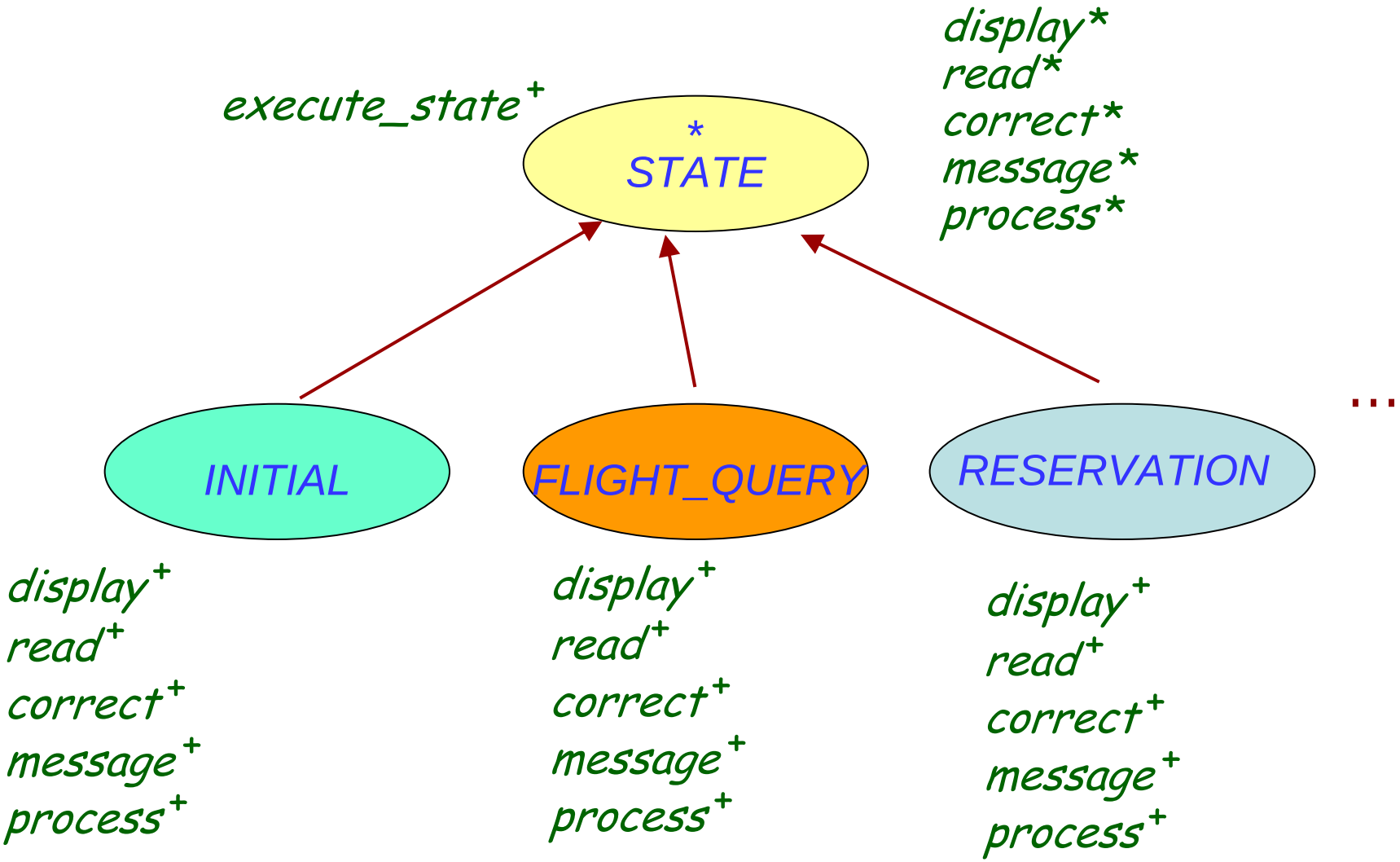


A polymorphic data structure!

Executing a session

```
execute_session is
        -- Run one session of application
    local
        current_state : STATE          -- Polymorphic!
        index : INTEGER
    do
        from
                index := initial
        until
                index = 0
        loop
                current_state := states [index ]

                current_state.execute_state

                index := transition [index, current_state.choice]
        end
    end
```

Class structure

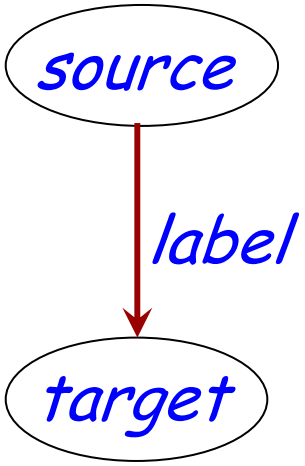


Other features of *APPLICATION*

```
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 number as the initial state.
    require
            1 <= number
            number <= states.upper
    do
            first_number := number
    end
```

More features of *APPLICATION*

```
        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
```



To build an application

Necessary states — instances of *STATE* — should be available.

Initialize application:

create *a.make* (*state_count*, *choice_count*)

Assign a number to every relevant state *s*:

a.put_state (*s*, *n*)

Choose initial state *n0*:

a.choose_initial (*n0*)

Enter transitions:

a.put_transition (*sou*, *tar*, *lab*)

May now run:

a.execute_session

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