# Requirements Checking for Object-Oriented Software Design with different Unified Modelling Language (UML) notations

## Use Case Notation, Sequence Diagrams, Regular Expressions and State Automata

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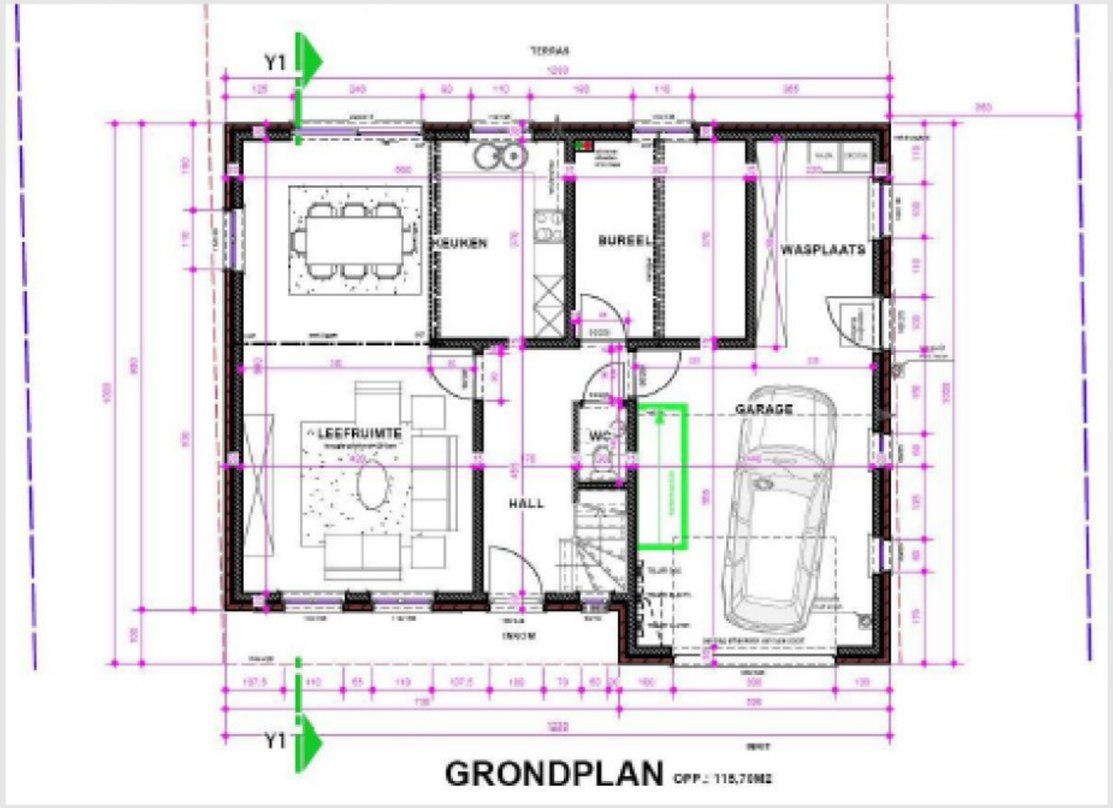
# What vs. How

## Requirements (“What?”)

- Detached or Semi-detached
- Style (classical, modern, . . . )
- Number of Floors
- Number of rooms of different types (bedrooms, bathrooms, . . . )
- Garage, Storage, . . .
- Cellar
- . . .

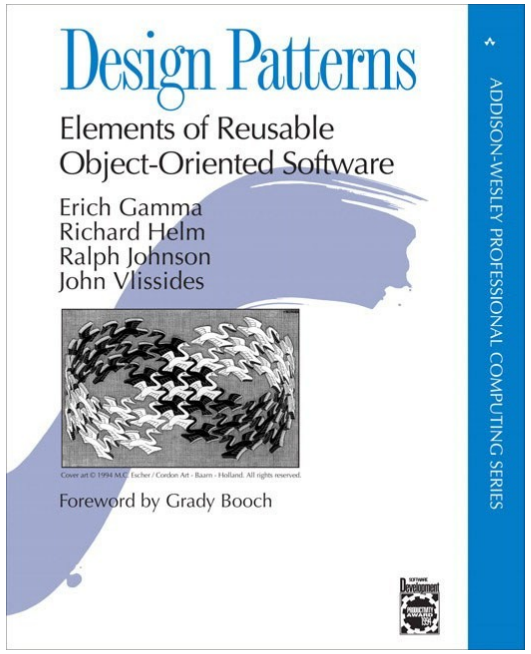
## Design (“How?”)



requirements
(i.e., a set of properties)

*satisfied by* → design

(may in turn serve as requirements ...)



Design Patterns

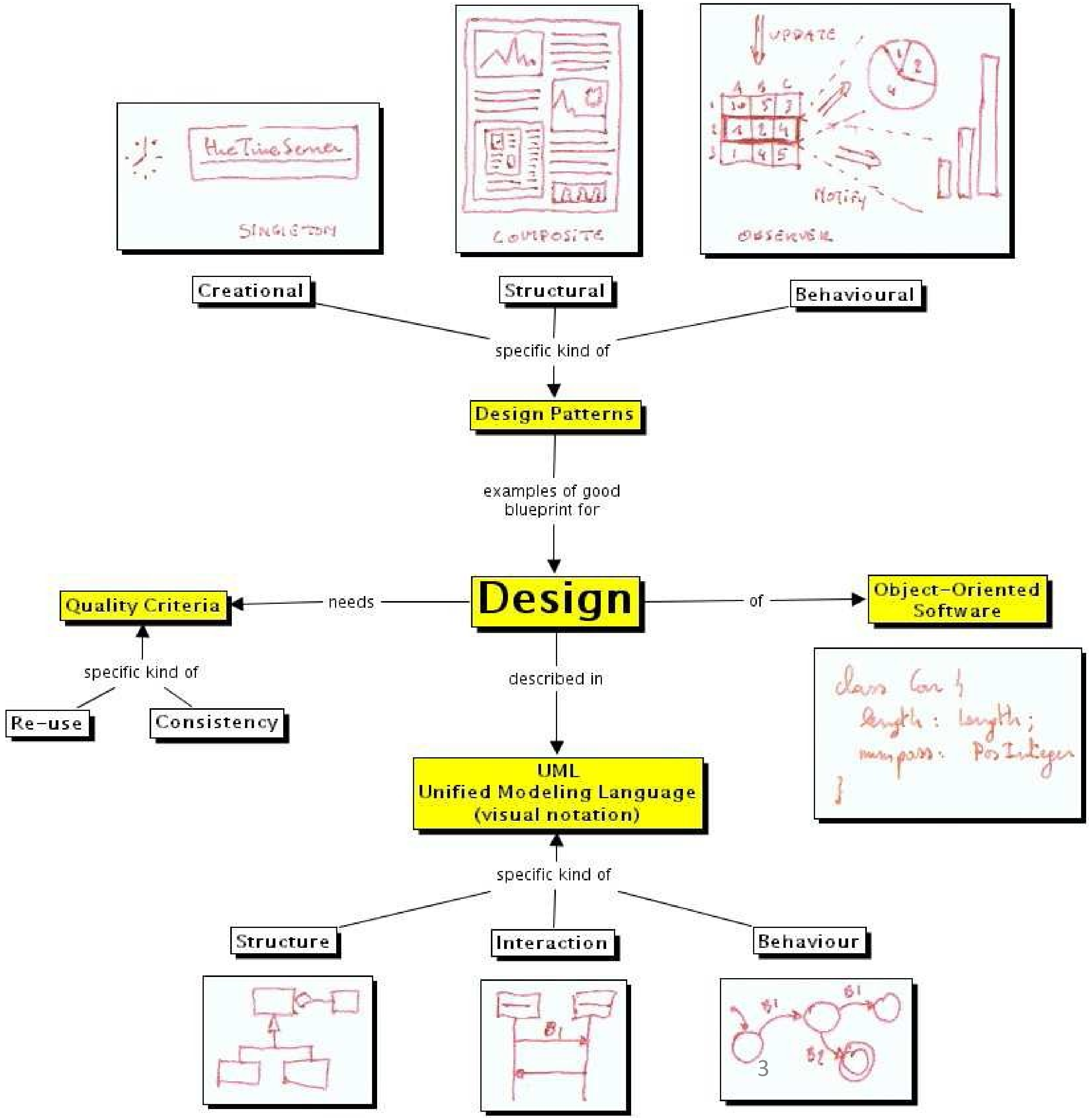
Elements of Reusable Object-Oriented Software

Erich Gamma
Richard Helm
Ralph Johnson
John Vlissides

Foreword by Grady Booch

ADDISON-WESLEY PROFESSIONAL COMPUTING SERIES

UNIFIED MODELING LANGUAGE™



OO Design Notations (UML) →

# Contents

- Railway Junction Controller (assignment)
- Class Diagrams
- Use Case Notation
- Sequence Diagrams
- Regular Expressions
- State Automata

# Sources/Background Material

- Use cases:
  http://www.cs.mcgill.ca/~joerg/SEL/COMP-533_Handouts_files/COMP-533%204%20Use%20Cases.pdf
- Class diagrams: http://www.uml-diagrams.org/class-diagrams-overview.html
- Sequence diagrams: http://www.uml-diagrams.org/sequence-diagrams.html
- Regular expressions: http://www.zytrax.com/tech/web/regex.htm
- Finite state automata:
  http://cs.stanford.edu/people/eroberts/courses/soco/projects/2004-05/automata-theory/basics.html
- Test out regular expressions online: https://regex101.com/

- Simple UML rendering tool: http://plantuml.com/

## Railway Junction Controller Requirements

The system (behaviour) to be built must satify the following requirements (properties):

- R1. By default, all traffic lights that prevent the entry to the junction are set to red for safety.
- R2. The railway segments continuously check for the presence of a train on that segment.
  As soon as a train is detected, a signal is sent to the controller.
- R3. The controller will process these incoming signals, and will put the traffic light of the requesting segment to green. This only when there is currently no train on the junction itself, and when the traffic light on the other entry to the junction is red too.
- R4. As soon as a train has entered the junction, all traffic lights for entry to the junction are put to red again.
- R5. If it is detected that the junction is clear again, new (or queued) requests are handled.
- R6. For safety, the signal to the traffic light is sent out every second (such that traffic lights can detect if there is a problem with the connection).

## Assignment

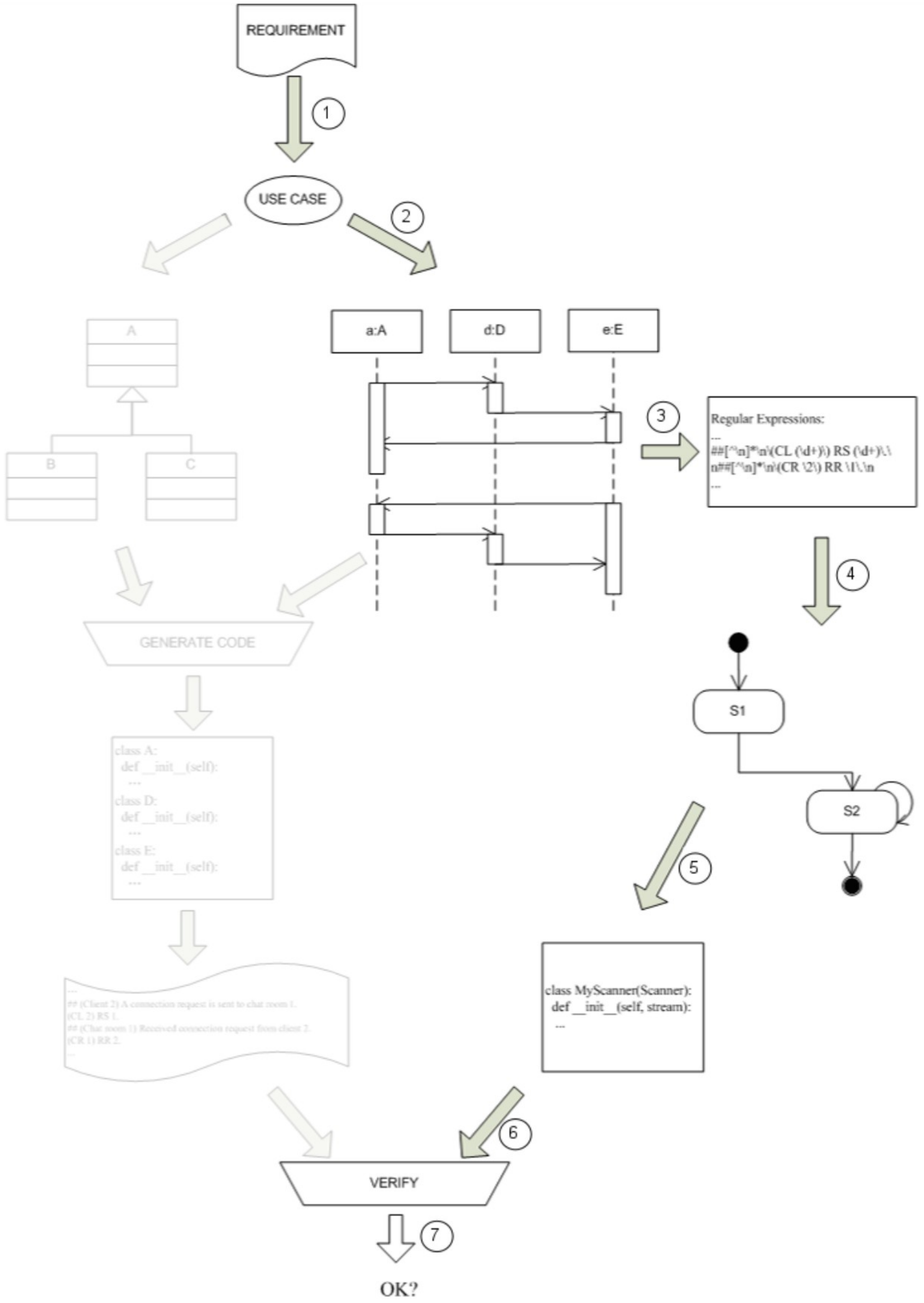
- You are given an **implementation** of a **railway junction controller**, which needs to set the traffic signals of the segments coming in to the junction.
- It is necessary to check whether or not the **specified requirements are satisfied**.
- You are, however, only given access to a **trace file of the execution**. This trace file contains behaviour information about the junction, such as all incoming signals, outgoing signals, and internal timers that get triggered, as a function of time.
- Due to this verbosity, and the total runtime of the execution, the file is quite long, and therefore validating the requirements is not to be done manually, but **automatically**.
- You will first model the given requirements using **Regular Expressions**, starting from **Use Cases** translated to **Sequence Diagrams** which you will translate to **Finite State Automata** recognizing the Regular Expressions.
  You will subsequently **encode** the FSAs to automatically verify, based on the given behaviour trace, whether the system implementation complies with the system specification given in the requirements below (and modelled visually in **Sequence Diagram** form). This is obviously only a test rather than a proof of requirements satisfaction.

# Assignment

The behaviour to be verified (given as use cases) is as follows:

- U1. When a train wants to enter the junction, it will **eventually** get a green light.
- U2. When a train enters the junction, all traffic lights to the junction become red.
- U3. **If a train is on the junction, all traffic lights will remain red until that train has left the junction.**
- U4. **If two trains are waiting to enter the junction at the same time, permission will be granted in order of arrival (i.e., the first train to arrive will get a green light, and the second one has to wait).** Simultaneous arrival?
- U5. The controller will send the traffic light signals out **every second**.

# Workflow



Regular Expressions:

```
...
##[^\n]*\n\(CL (\d+)\) RS (\d+)\.\
n##[^\n]*\n\(CR \2\) RR \1\.\n
...
```

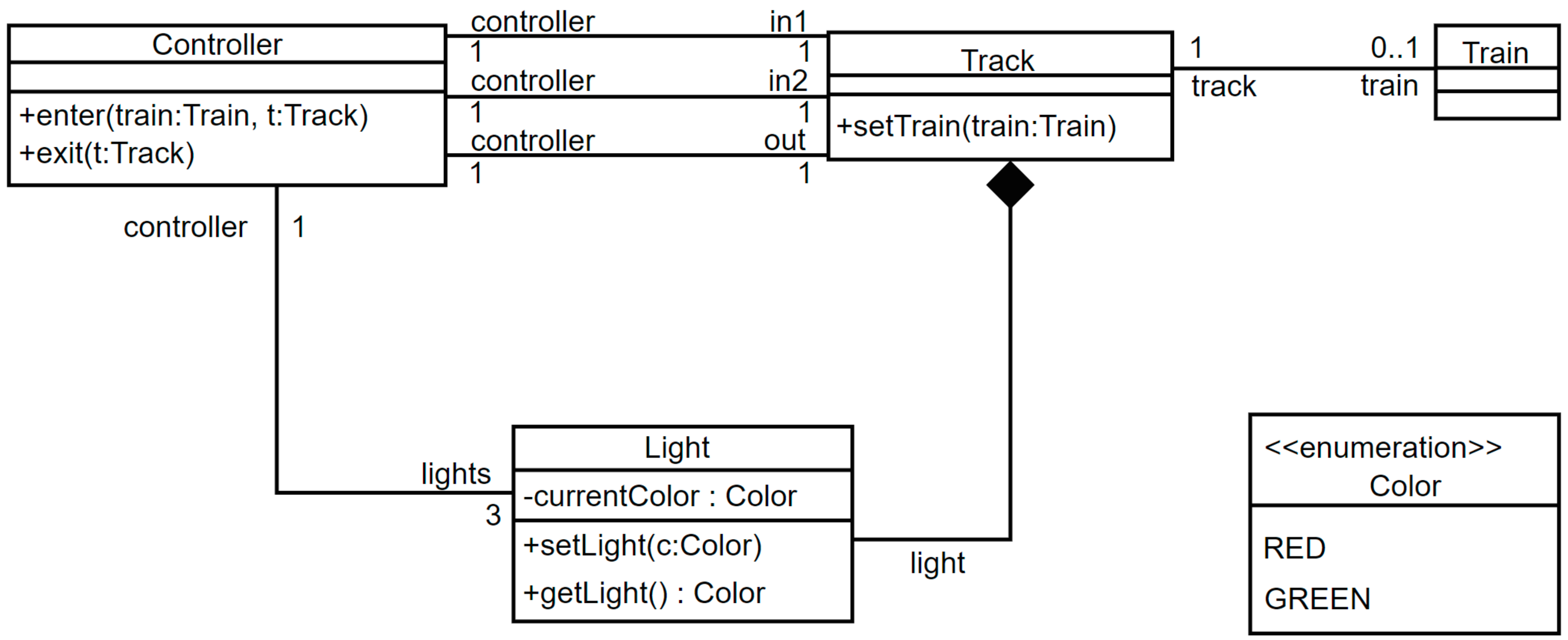
```
class A:
  def __init__(self):
    ...
class D:
  def __init__(self):
    ...
class E:
  def __init__(self):
    ...
```

```
...
## (Client 2) A connection request is sent to chat room 1.
(CL 2) RS 1.
## (Chat room 1) Received connection request from client 2.
(CR 1) RR 2.
...
```

```
class MyScanner(Scanner):
  def __init__(self, stream):
    ...
```

## Class Diagrams

- Structure of the system (Object-Oriented)
  instantiation: Object Diagrams



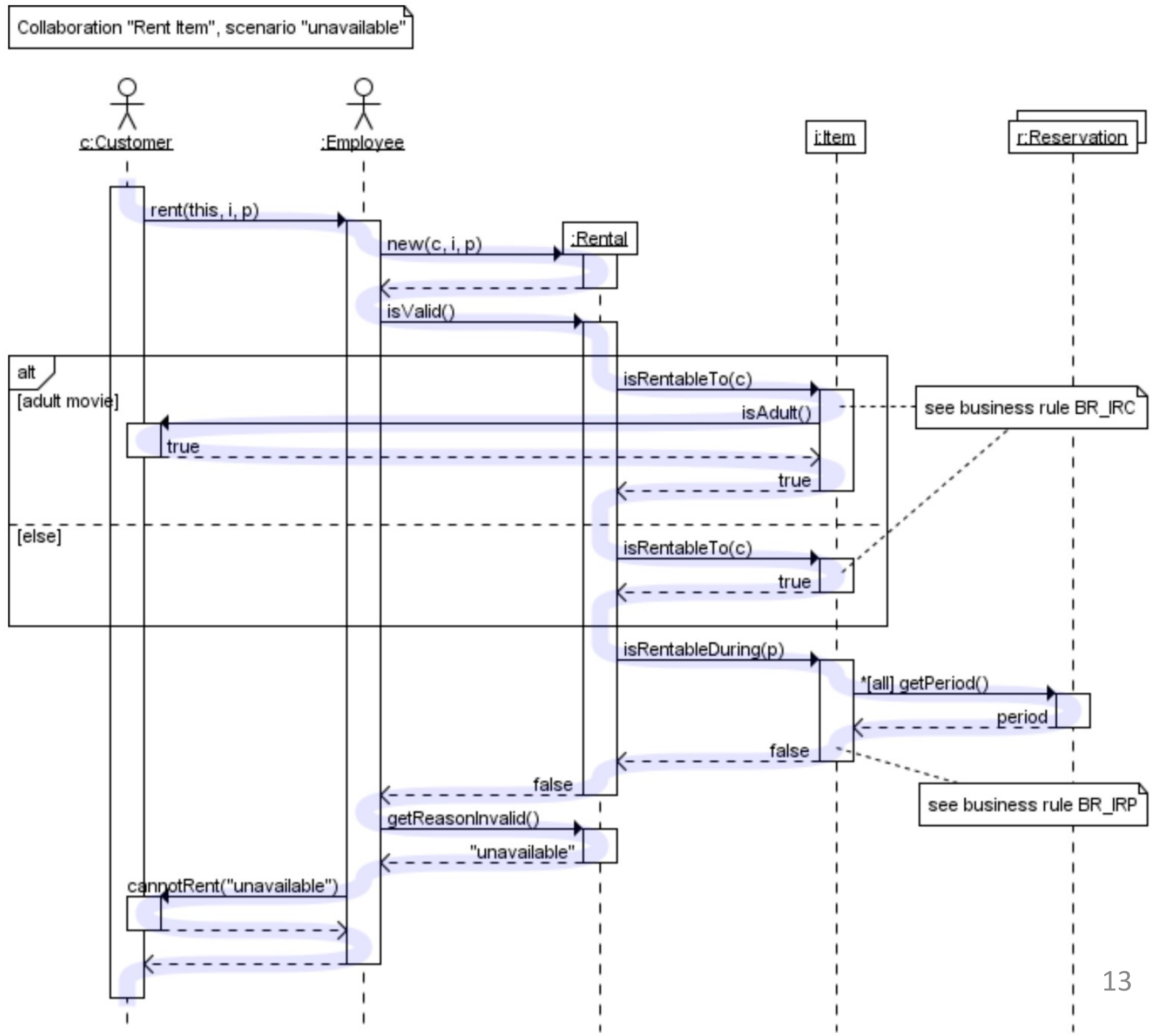
## Use Cases

- Document functional requirements of the system
    - interactions between system and **environments** to achieve **user goals**
- Understandable for (non-technical) client
    - semi-formal
    - complete, consistent and verifiable
- Business viewpoint
    - **who** (actors) does **what** (interaction) with **what purpose** (goal)?
    - no implementation details: **black box**
- See Joerg Kienzle and Shane Sendall's presentation
    - http://www.cs.mcgill.ca/~joerg/SEL/COMP-533_Handouts_files/COMP-533%204%20Use%20Cases.pdf
      (slide 8 -> …)

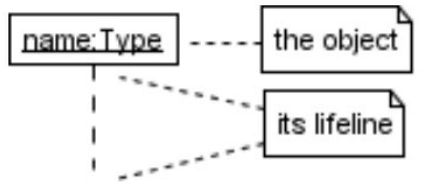
# Sequence Diagrams

- Behaviour of the system
    - Interaction diagram
- Complementary to Class Diagrams (structure vs. behaviour)
- Complementary to Use Cases (“what?” vs. “how?”)

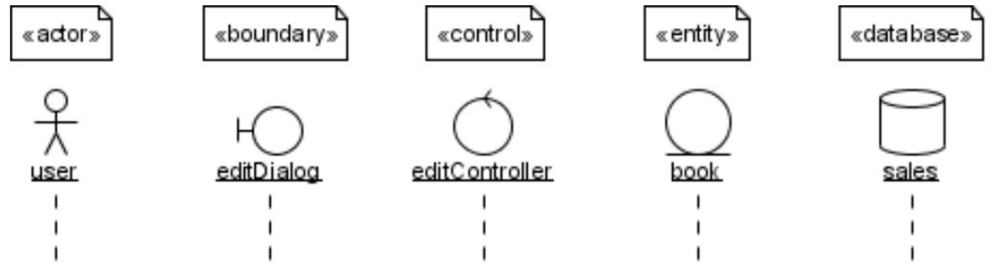
# Sequence Diagrams

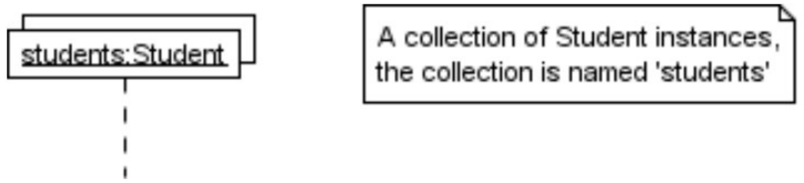


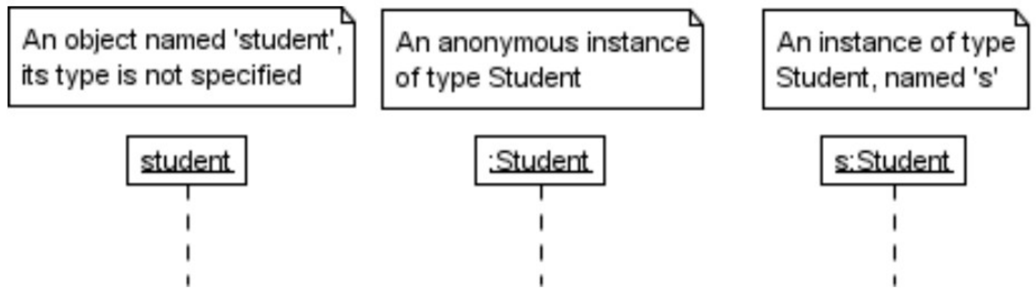
# Objects and Lifelines

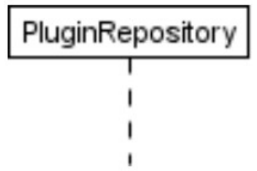


types of objects:




students:Student
A collection of Student instances, the collection is named 'students'

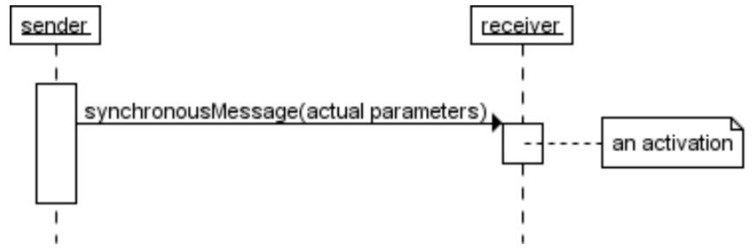

An object named 'student', its type is not specified
An anonymous instance of type Student
An instance of type Student, named 's'
student
:Student
s:Student



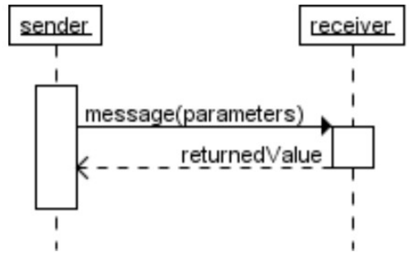
class object
(only use class messages)

## Messages (1)

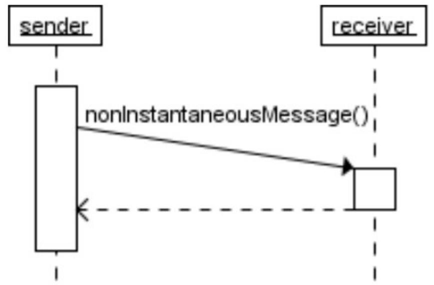
- Synchronous:



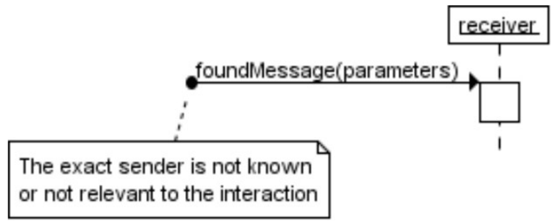
- Returned value:



- Not instantantaneous:

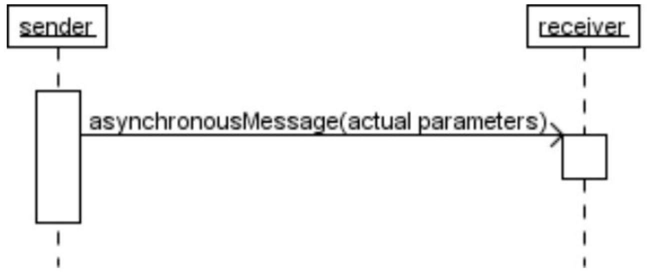


- Found message:

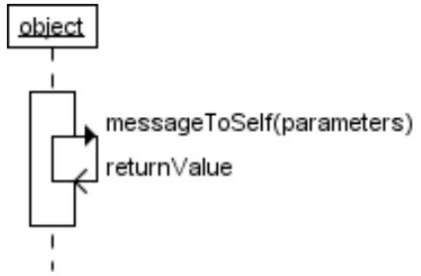

receiver
foundMessage(parameters)
The exact sender is not known
or not relevant to the interaction

## Messages (2)

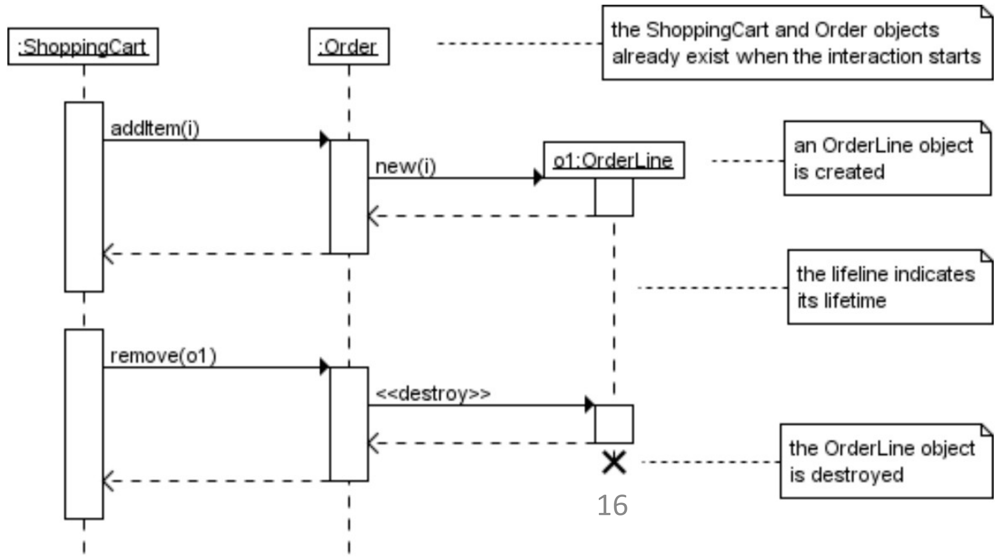
- Asynchronous:



- Message to self:

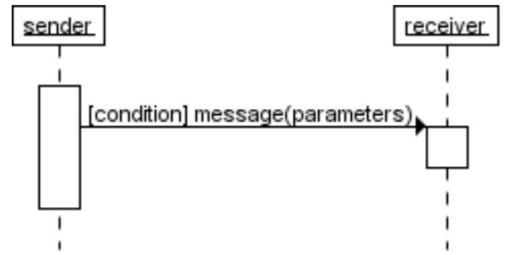


- Object creation/destruction:

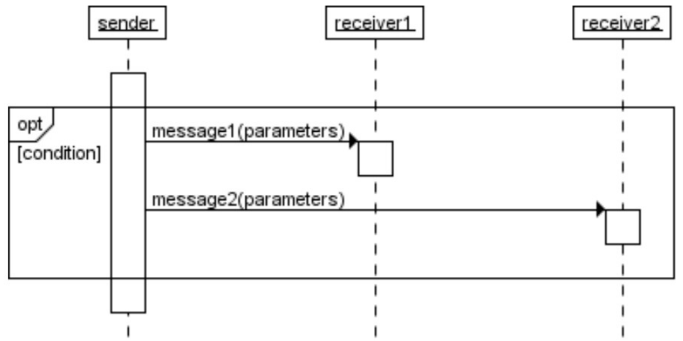

:ShoppingCart
:Order
the ShoppingCart and Order objects already exist when the interaction starts
addItem(i)
new(i)
o1:OrderLine
an OrderLine object is created
the lifeline indicates its lifetime
remove(o1)
<<destroy>>
the OrderLine object is destroyed

# Conditional Interaction

- Message with guard:

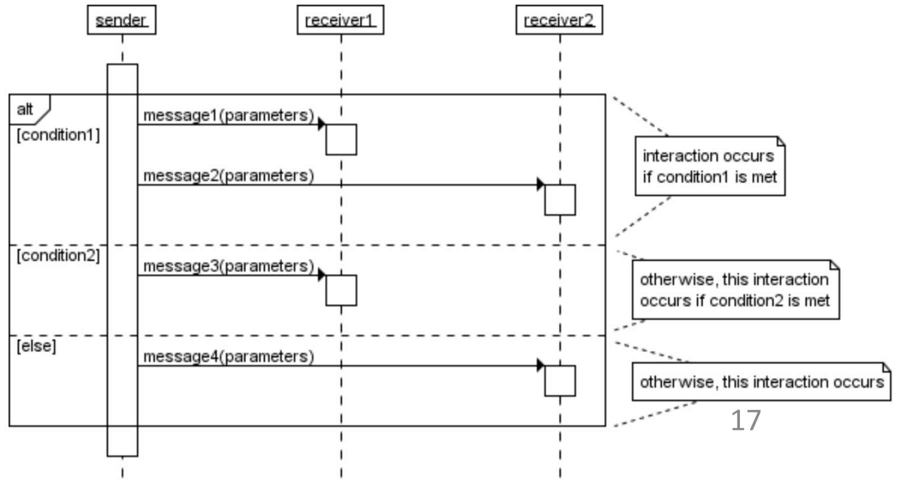


- Multiple messages:



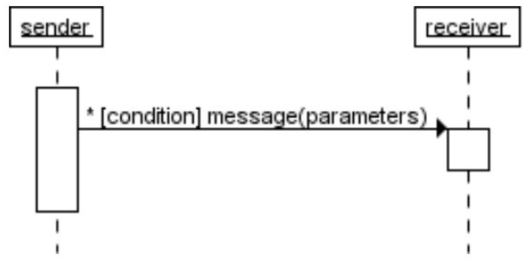
"combined fragment"

- Alternative interactions:

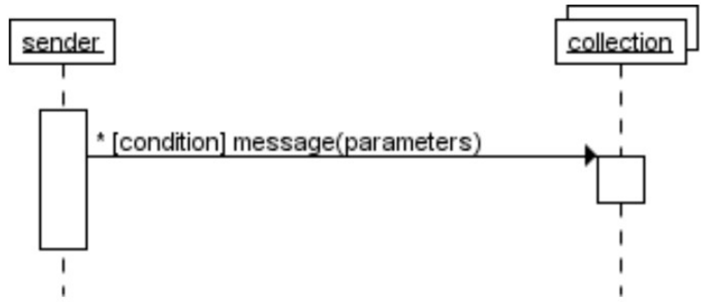


# Repeated Interaction (1)

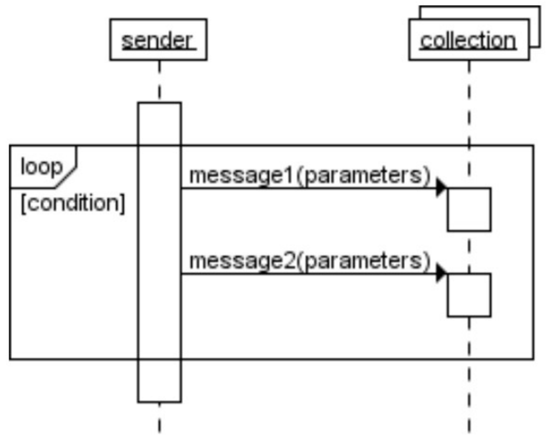
- Repeated message:



- Elements in a collection:

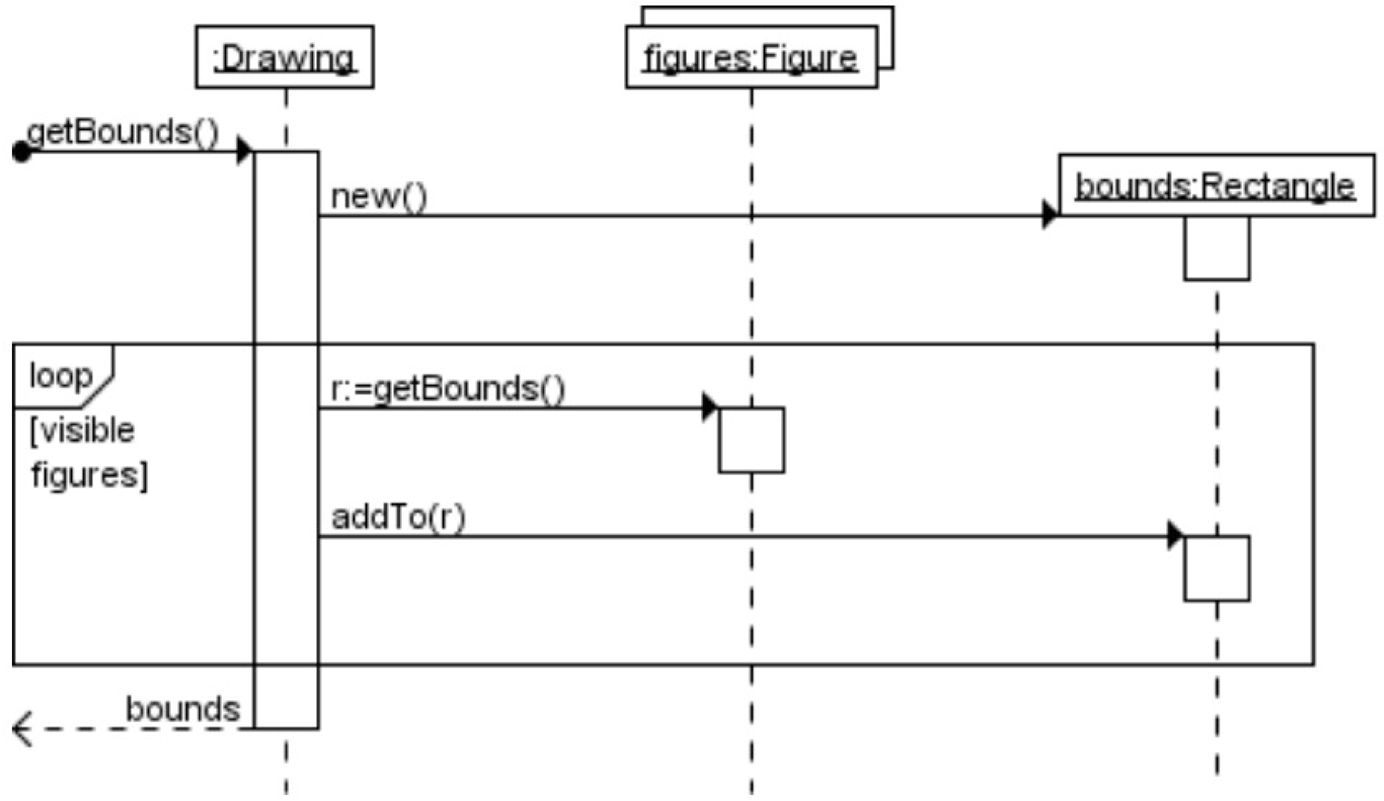


- Combined fragment:



# Repeated Interaction (2)

- Example:



# Regular Expressions

## Search pattern for finding occurrences in a string

- [eE] stands for e or E.
- [a-z] stands for one of the characters in the range a to z.
- ^ means "match at the beginning of a line/string".
- $ means "match at the end of the line/string".
- X|Y means "match either X or Y", with X and Y both sub-expressions.
- [^x] means not x, so [^E].*\n matches every line except those that start with the E character
- . matches any single character.
- X? matches 0 or 1 repetitions of X.
- X* matches 0 or more repetitions of X.
- X+ matches 1 or more repetitions of X.
- \ is used to escape meta-characters such as (. If you want to match the character (, you need the pattern \(.
- The ( and ) meta-characters are used to memorize a match for later use. They can be used around arbitrarily complex patterns. For example ([0-9]+) matches any non-empty sequence of digits. The matched pattern is memorized and can be referred to later by using \1. Following matched bracketed patterns are referred to by \2, \3, etc. Note that you will need to encode powerful features such as this one by adding appropriate actions (side-effects) to your automaton encoding the regular expression. This can easily be done by storing a matched pattern in a variable and later referring to it again.

# Example: Railway Junction Controller Trace

Write regular expressions (refer to the format of the given output trace) for verifying the above use cases. We use abbreviations to shorten the messages that you need to recognize in your RegExp/FSA. Here are the mappings:

E := A train **E**nters the specified segment (En with n the segment number)

R := A **R**ed signal is sent to the specified segment

G := A **G**reen signal is sent to the specified segment

X := A train leaves the specified segment

Beyond that, each segment has a simple encoding:

1 := left incoming railway segment

2 := right incoming railway segment

3 := outgoing railway segment

## Example: Regular Expression

*If a train wants to enter the junction, it will eventually get a green light.*

Regular expression pattern (for segment 1):
^((([^E].*)|(E [23]))\n)*(**E 1**\n(.*\n)* **G 1**\n((([^E].*)|(E [23]))\n)*)*$

For segment 2:
^((([^E].*)|(E [13]))\n)*(**E 2**\n(.*\n)* **G 2**\n((([^E].*)|(E [13]))\n)*)*$

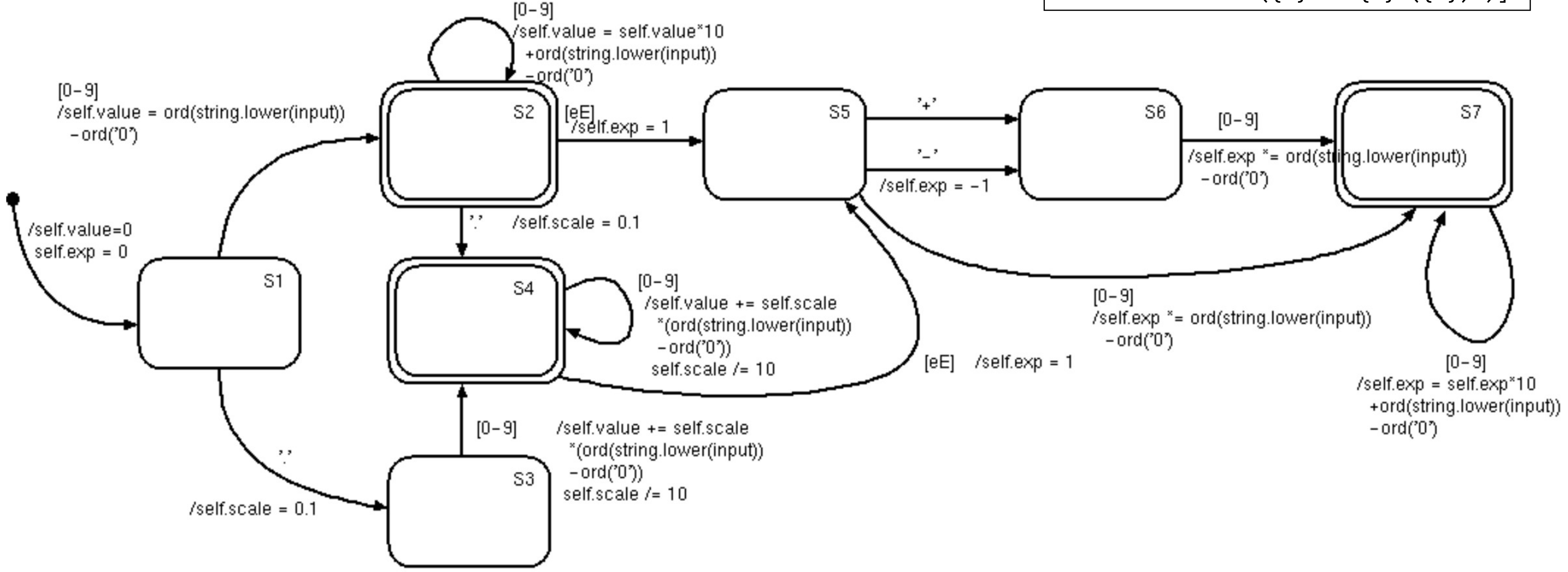
Anything except for E 1:
(([^E].*)|(E [23]))\n

## Finite State Automata

- Discrete states + transitions
- Change **state** in response to **external inputs**: **transition**
- Can be used to encode regular expressions

# Finite State Automata Example

```
D              [0-9]
E              [eE][+-]?({D})+
Number         [({D}+{E}?)
                ({D}*'.'{D}+({E})?)
                ({D}+'.'{D}*({E})?)]
```


S1
S2
S3
S4
S5
S6
S7
/self.value=0
self.exp = 0
[0−9]
/self.value = ord(string.lower(input))
−ord('0')
[0−9]
/self.value = self.value*10
+ord(string.lower(input))
−ord('0')
[eE]
/self.exp = 1
'.'
/self.scale = 0.1
'.'
/self.scale = 0.1
[0−9]
/self.value += self.scale
*(ord(string.lower(input))
−ord('0'))
self.scale /= 10
[0−9]
/self.value += self.scale
*(ord(string.lower(input))
−ord('0'))
self.scale /= 10
[eE]
/self.exp = 1
'+'
'−'
/self.exp = −1
[0−9]
/self.exp *= ord(string.lower(input))
−ord('0')
[0−9]
/self.exp *= ord(string.lower(input))
−ord('0')
[0−9]
/self.exp = self.exp*10
+ord(string.lower(input))
−ord('0')

# Finite State Automata Implementation (semantics)

```
class Scanner:
 """
  A simple Finite State Automaton simulator.
  Used for scanning an input stream.
 """
 def __init__(self, stream):
  self.set_stream(stream)
  self.current_state=None
  self.accepting_states=[]

 def set_stream(self, stream):
  self.stream = stream

 def scan(self):
  ...
```

```
def scan(self):

 self.current_state=self.transition(self.current_state, None)

 if __trace__:
   print "\ndefault transition --> "+self.current_state

 while 1:
   # look ahead at the next character in the input stream
   next_char = self.stream.showNextChar()

   # stop if this is the end of the input stream
   if next_char == None: break

   if __trace__:
     print str(self.stream)
     if self.current_state != None:
       print "transition "+self.current_state+" -| "+next_char,

   # perform transition and its action to the appropriate new state
   next_state = self.transition(self.current_state, next_char)

   if __trace__:
     if next_state == None:
       print
     else:
       print "|-> "+next_state

   # stop if a transition was not possible
   if next_state == None:
     break
   else:
     self.current_state = next_state
     # perform the new state's entry action (if any)
     self.entry(self.current_state, next_char)

   # now, actually consume the next character in the input stream
   next_char = self.stream.getNextChar()

 if __trace__:
   print str(self.stream)+"\n"

 # now check whether to accept consumed characters
 success = self.current_state in self.accepting_states
 if success:
  self.stream.commit()
 else:
  self.stream.rollback()
 return success
```

## Finite State Automata: encoding a specific FSA

```
class NumberScanner(Scanner):

 def __init__(self, stream):

   # superclass constructor
   Scanner.__init__(self, stream)

   # define accepting states
   self.accepting_states=["S2","S4","S7"]

 def __str__(self):

   return str(self.value)+"E"+str(self.exp)

 def entry(self, state, input):

   pass
```

```
def transition(self, state, input):
   """
   Encodes transitions and actions
   """

   if state == None:
      # action
      # initialize variables
      self.value = 0
      self.exp = 0
      # new state
      return "S1"

   elif state == "S1":
    if input  == '.':
      # action
      self.scale = 0.1
      # new state
      return "S3"
    elif '0' <= input <= '9':
      # action
      self.value = ord(string.lower(input))-ord('0')
      # new state
      return "S2"
    else:
      return None

   elif state == "S2":
    if input  == '.':
      # action
      self.scale = 0.1
      # new state
      return "S4"
    elif '0' <= input <= '9':
      # action
      self.value = self.value*10+ord(string.lower(input))-ord('0')
      # new state
      return "S2"
    elif ...
```