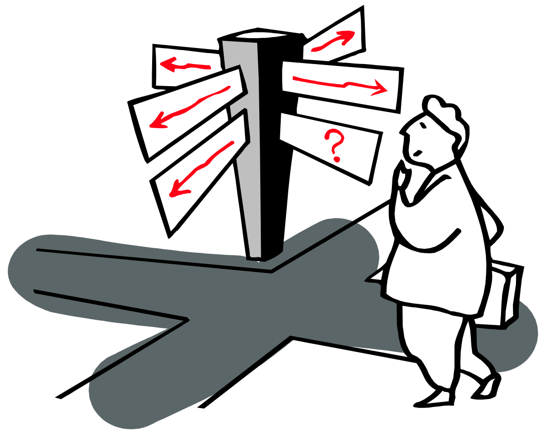
CHAPTER 5 – Design by Contract



- Introduction
  + When, Why & What
  + Pre & Postconditions + Invariants
    - Example: Stack
- Implementation
  + Redundant Checks vs. Assertions
  + Exception Handling
  + Assertions are not…
- Theory
  + Correctness formula
  + Weak and Strong
  + Invariants
  + Subclassing and Subcontracting
    - The Liskov Substitution Principle
    - Behavioral subtyping
- Conclusion
  + How Detailed?
  + Tools: The Daikon Invariant Detector
  + Modern Application: Rest API
  + Example: Banking
  + Design by Contract vs. Testing

Literature

- [Ghez02], [Somm05], [Pres00]
  + Occurences of “contract”, “assertions”, “pre” and “postconditions”, via index
- [Meye97] Object-Oriented Software Construction, B. Meyer, Prentice Hall, Second Edn., 1997.
  + An excellent treatment on the do’s and don’ts of object-oriented development. Especially relevant are the chapters 6, 11-12

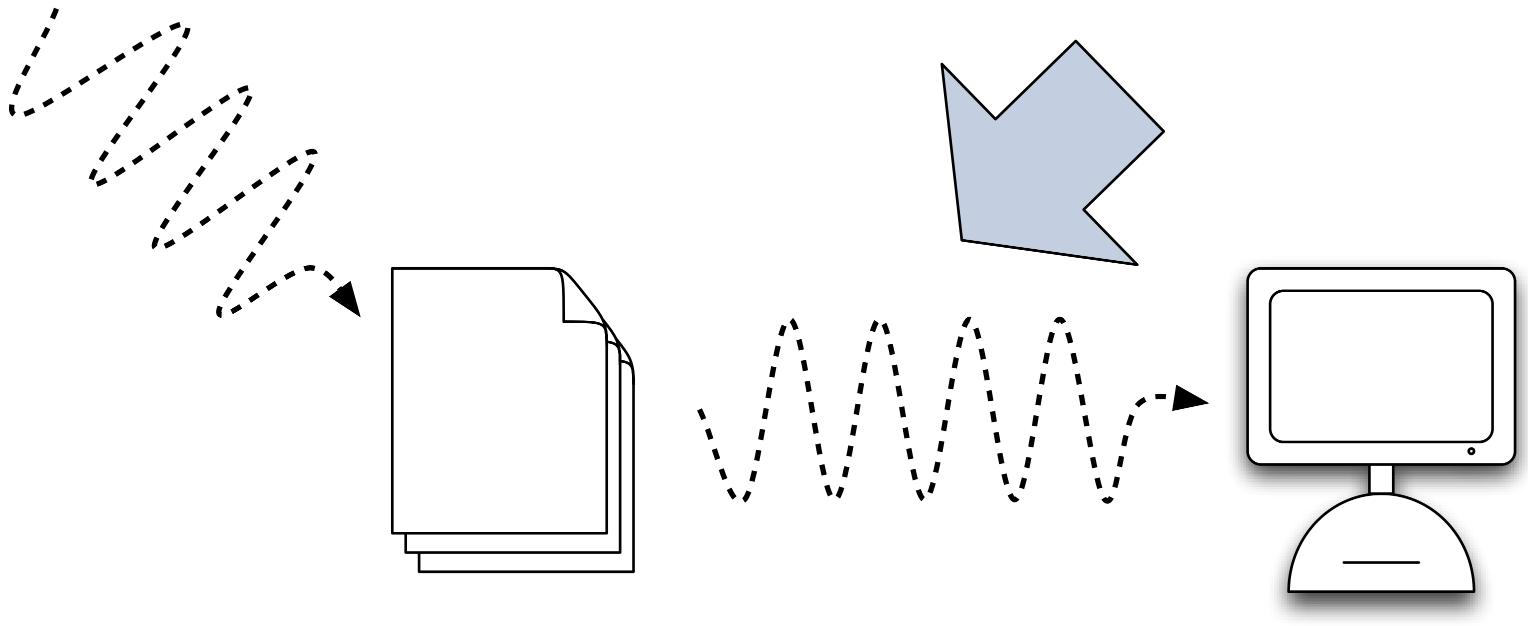
Copies of the following two articles are available from the course web-site.

- [Jeze97] “Put it in the contract: The lessons of Ariane”, Jean-Marc Jézéquel and Bertrand Meyer, IEEE Computer, January 1997, Vol30, no. 2, pages 129-130. A slightly different version of this article is available at http://www.irisa.fr/pampa/EPEE/Ariane5.html
  + A (heatedly debated) column arguing that Design by Contract would have prevented the crash of the first Ariane5 missile.
- [Garl97] “Critique of ‘Put it in the contract: The lessons of Ariane’”, Ken Garlington. See http://home.flash.net/~kennieg/ariane.html
  + An article providing counterarguments to the former. Yet by doing so gives an excellent comparison with Testing and Code Inspection.

Modern applications - Testing REST API

+ "Simplifying Microservice testing with Pacts", Ron Holshausen. https://dius.com.au/2014/05/19/simplifying-micro-service-testing-with-pacts/
  - Tutorial: https://docs.pact.io

When Design by Contract?



Mistakes are possible (likely!?)

- while transforming requirements into a system
- while system is changed during maintenance

Why Design By Contract?

- What's the difference with Testing?
  + Testing tries to *diagnose* (and cure) defects after the facts.
  + Design by Contract tries to *prevent* certain types of defects.
    > "Design by Contract" falls under Implementation/Design

- Design by Contract is particularly useful in an Object-Oriented context
  - (Or component-oriented, service-oriented, …)
  + preventing errors in interfaces between classes, components, services (incl. subclass and superclass via subcontracting)
  + preventing errors while reusing classes, components, services (incl. evolving systems, thus incremental and iterative development)
    * Example of the Ariane 5 crash

Use Design by Contract in combination with Testing!

What is Design By Contract?

"View the relationship between two classes as a formal agreement, expressing each party's rights and obligations." ([Meye97], Introduction to Chapter 11)

- Each party expects benefits (rights) and accepts obligations
- Usually, one party's benefits are the other party's obligations
- Contract is declarative: it is described so that both parties can understand *what* service will be guaranteed without saying *how*.

- Example: Airline reservation

	Obligations	Rights
Customer (Client Class)	- Be at Brussels airport at least 1 hour before scheduled departure time - Bring acceptable baggage - Pay ticket price	- Reach Chicago
Airline (Supplier Class)	- Bring customer to Chicago	- No need to carry passenger who is late, - has unacceptable baggage, - or has not paid ticket

Pre- and Post-conditions + Invariants

obligations are expressed via pre- and post-conditions

"If you promise to call me with the precondition satisfied, then I, in return promise to deliver a final state in which the postcondition is satisfied."

pre-condition: {x >= 9}

component: {x := x + 5}

post-condition: {x >= 13}

... and invariants

"For all calls you make to me, I will make sure the invariant remains satisfied."

invariant: {x >= y}

pre-condition: {x > 0, y > 0}

component: {x := x + y}

pre-condition: {x > 0, y < 0}

component: {x := x - y}

Quiz: Whose fault is it when a pre-condition is NOT satisfied?

Example: Stack

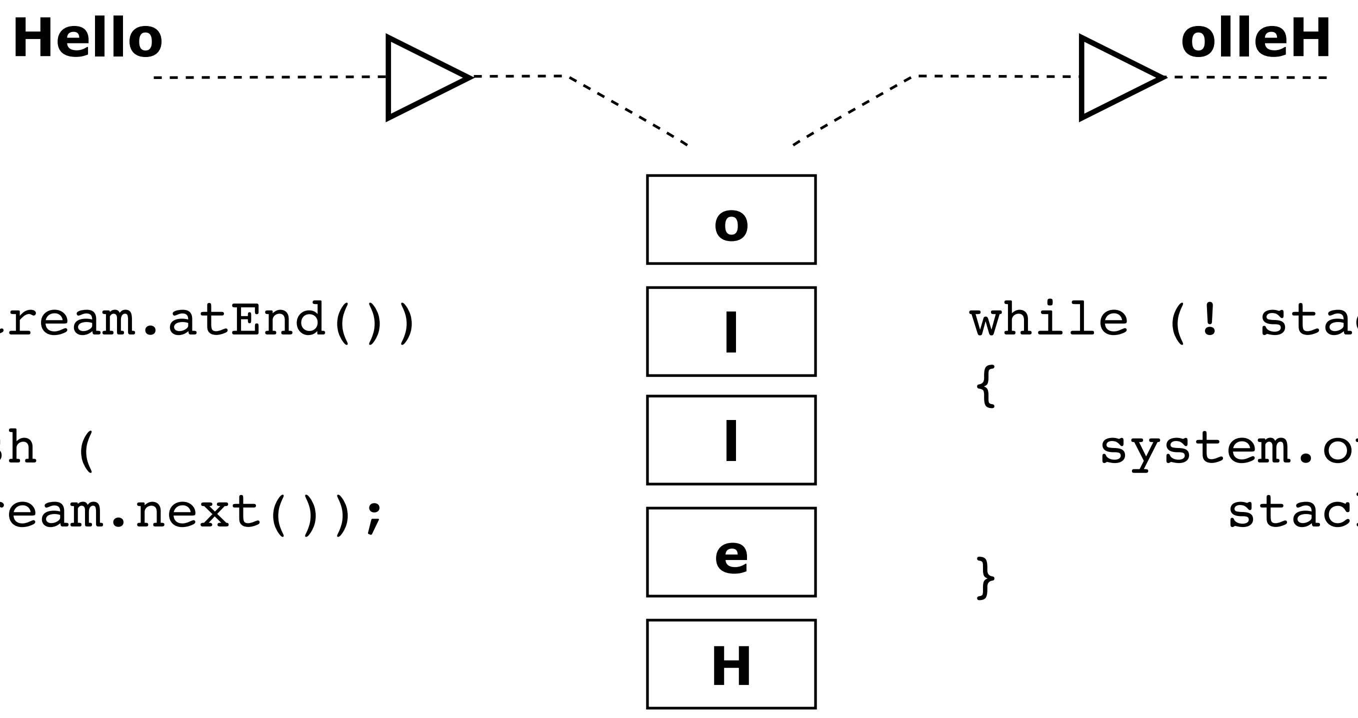
Given

  A stream of characters, length unknown

Requested

  Produce a stream containing the same characters but in reverse order

  Specify the necessary intermediate abstract data structure



```
while (! inStream.atEnd())
{
    stack.push (
        inStream.next());
}
```

```
while (! stack.isEmpty())
{
    system.out.print (
        stack.pop());
}
```

Example: Stack Specification

```
class stack
    invariant: (isEmpty (this)) or
        (! isEmpty (this))
```

Implementors of stack promise that invariant will be true after all methods return (incl. constructors)

```
    public char pop ()
        require: ! isEmpty (this)
            ensure: true
```

Clients of stack promise precondition will be true before calling pop()

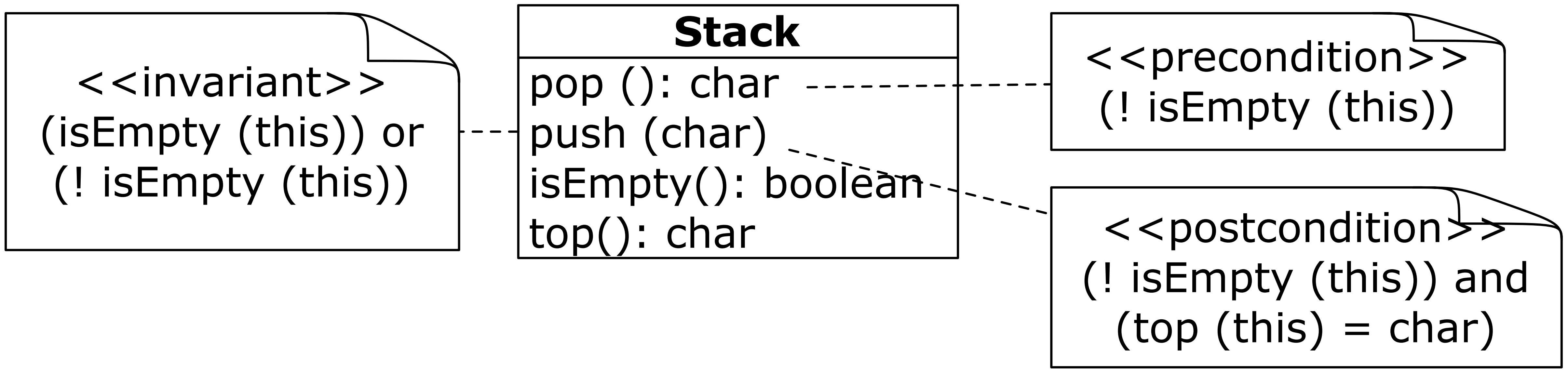
```
    public void push (char)
        require: true
        ensure: (! isEmpty (this))
            and (top (this) = char)
```

Implementors of stack promise postcondition will be true after push() returns

```
    public void top (char) : char
        require: ...
        ensure: ...
    public void isEmpty () : boolean
        require: ...
        ensure: ...
```

Left as an exercise

Design by Contract in UML



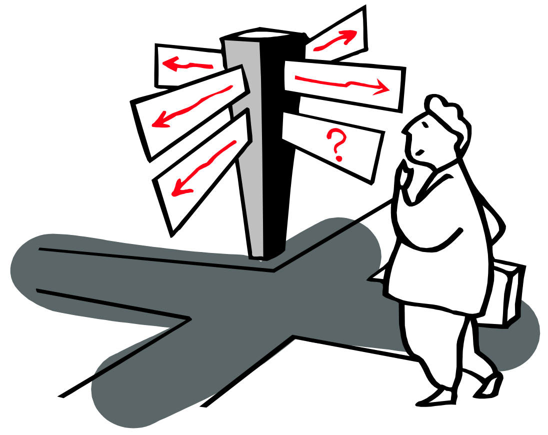
So what: isn’t this pure documentation?
Who will
- (a) Register these contracts for later reference (the book of laws)?
- (b) Verify that the parties satisfy their contracts (the police)?

Answer
- (a) The source code
- (b) The running system

Q

Quiz: What happens when a pre-condition is NOT satisfied?

CHAPTER 6 – Design by Contract



Redundant Checks

Redundant checks: naive way for including contracts in the source code

```
public char pop () {
    if (isEmpty (this)) {
        ... //Error-handling
} else {
        ...}
```

This is redundant code: it is the responsibility of the client to ensure the pre-condition!

Redundant Checks Considered Harmful

- Extra complexity
  Due to extra (possibly duplicated) code
  ... which must be verified as well.
- Performance penalty
  Redundant checks cost extra execution time.
- Wrong context
  How severe is the fault? How to remedy the situation? A service provider cannot asses the situation, only the consumer can.

Assertions

+ assertion = any boolean expression we expect to be true at some point.

- Assertions …
  + Help in writing correct software
    * formalizing invariants, and pre- and post-conditions
  + Aid in maintenance of documentation
    * specifying contracts IN THE SOURCE CODE
    * tools to extract interfaces and contracts from source code
  + Serve as test coverage criterion
    * Generate test cases that falsify assertions at run-time
  + Should be configured at compile-time
    * to avoid performance penalties with trusted parties
    * What happens if the contract is not satisfied?

Quiz: What happens when a pre-condition is NOT satisfied?
> = What should an object do if an assertion does not hold?
  * ***Throw an exception.***

Assertions in Source Code

```
public char pop() throws AssertionException {
    char tempResult;
    my_assert(!this.isEmpty());
    tempresult = _store[_size--];
    my_assert(invariant());
    my_assert(true); //empty postcondition
      return tempResult;
}


private boolean invariant() {
    return (_size >= 0) && (_size <= _capacity);}


private void my_assert(boolean assertion)
    throws AssertionException {
    if (!assertion) {
        throw new AssertionException
            ("Assertion failed");}
}
```

Should be turned on/off via compilation option

Exception Handling

```
public class AssertionException extends Exception {
    AssertionException() { super(); }
    AssertionException(String s) { super(s); }
}



static public boolean testEmptyStack() {
    ArrayStack stack = new();
    try {
        // pop() will raise an exception
        stack.pop();


    } catch(AssertionException err) {
        // we should get here!
        return true;
    };

    return false;
}
```

If an ‘AssertionException’ is raised within the try block ...

... we will fall into the ‘catch’ block

Assertions are not…

- Assertions look strikingly similar yet are different from …

  + Redundant Checks
    - Assertions become part of a class interface
    - Compilation option to turn on/off

  + Checking End User Input
    - Assertions check software-to-software communication,
      not software-to-human

  + Control Structure
    - Raising an exception is a control structure mechanism
    - … violating an assertion is a fault
      > precondition violation: responsibility of the client of the class
      > postcondition violation: responsibility of the supplier of the class
        * Only turn off assertions with trusted parties
        * Tests must verify whether exceptions are thrown

Programming Language Support

- Eiffel
  + Eiffel is designed as such … but only used in limited cases

- C++
  + assert() in C++ assert.h does not throw an exception
  + It’s possible to mimic assertions (incl. compilation option) in C++
  + Documentation extraction is more difficult but feasible

- Java
  + ASSERT is standard since Java 1.4
    ... however limited “design by contract” only; acknowledged by Java designers
    - https://docs.oracle.com/javase/7/docs/technotes/guides/language/assert.html
  + Documentation extraction using JavaDoc annotations

- … Other languages
  + Possible to mimic; compilation option requires language idioms
  + Documentation extraction is possible (style Javadoc)

Two Implementation Issues

- 1) The use of 'previous' or 'old' state
  + sometimes postconditions compare exit state with starting state

```
public char pop ()
  require: ! isEmpty (this)
  ensure: (top (old) = char)
    and (size (old) = size (this) + 1)
```

Use 'old' as a way to refer to the starting state of the receiver

  + Eiffel has a pseudo variable 'old'
  + Mimicking assertions in other languages?
    - store 'old' state in temporary variables

- 2) Invoking operations within assertions
  + Assertions may invoke operations with pre- and postconditions
    - overhead + cycles lead to infinite loops
  + Eiffel switches off assertions when checking assertions
  + Mimicking assertions in other languages?
    - Cumbersome using language idioms and class variable
      … best to avoid cycles

Testing Issues

+ Pre- and post-conditions are part of the interface of a component.
    - Part of black-box testing, not white-box testing
        > Do *not* include assertions in basis-path testing
        > Borderline case: include assertions in condition testing

+ Example

```
public char pop() throws AssertionException {
    assert(!this.isEmpty());
    return _store[_size--];
}
```

+ basis-path testing: cyclomatic complexity = 1; 1 path can cover the control-flow
    - (test case 1 = non-empty stack / value on the top)
+ condition testing: 2 inputs cover all conditions
    - (test case 1 = non-empty stack / value on the top
    - (test case 2 = empty stack / assertion exception)

See Next Week
(Chapter 6. Testing)

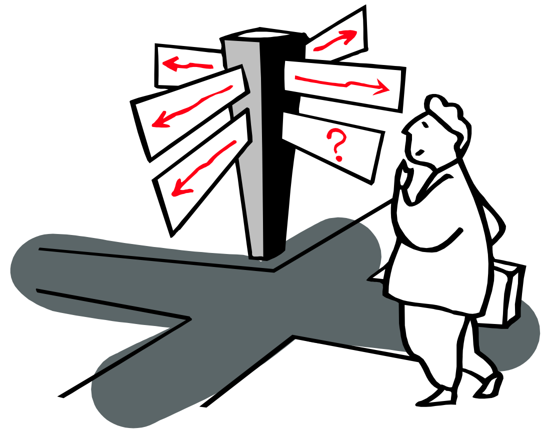
Compiler Checks?

How much assertion monitoring is needed?

All	**None**
Especially during development Too costly during production runs	Fully trusted system Metaphor “sailing without life-jacket”

- Rule of thumb
  + *** At least monitor the pre-conditions.
    - Make sure that verifying pre-conditions is fast!
    - Do not rely on switching off monitoring to gain efficiency
    - Profile performance to see where you loose efficiency
      > First do it, then do it right, then do it fast!

CHAPTER 6 – Design by Contract



Correctness Formula

a.k.a. *Hoare triples*

Let:

A be an *operation* (defined on a class C)

{P} and {Q} are *properties* (expressed via predicates, i.e functions returning a boolean)

Then:

{P} A {Q}

is a *Correctness Formula* meaning

"Any execution of A starting in a state where P holds, will terminate in a state where Q holds"

Example: ∀ x positive Integer

{x >= 9} x := x + 5 {x >=13}

See within 2 weeks (Chapter 7. Formal Specification)

Weak and Strong

- (Note: “weaker” and “stronger” follow from logic theory)

- Let {P1} and {P2} be conditions expressed via predicates
  - + {P1} is stronger then {P2} iff
    - - {P1} <> {P2}
    - - {P1} ⇒ {P2}
  - + example
    - - {x >= 9} is stronger then {x >= 3}
  - + {false} is the strongest possible condition
    [(not {false}) or {X} is always true]
  - + {true} is the weakest possible condition
    [(not {X}) or {true} is always true]

- *Remember: {P1} ⇒ {P2}*

  is the same as (not {P1}) or {P2}

P1	TRUE	FALSE	TRUE	FALSE
P2	TRUE	TRUE	FALSE	FALSE
{P1} ⇒ {P2}	TRUE	TRUE	FALSE	TRUE
(not {P1}) or {P2}	TRUE	TRUE	FALSE	TRUE

Weak and Strong: Quiz

- {P} A {Q} is a specification for operation A
  + You, as a developer of A must guarantee that once {P} is satisfied and A is invoked it will terminate in a situation where {Q} holds
  + If you are a lazy developer, would you prefer
    - a weak or a strong precondition {P}?
    - a weak or a strong postcondition {Q}?

	weak	strong	don’t know
precondition {P}			
postcondition {Q}			

Weak or Strong (Preconditions)

- Given correctness formula: {P} A {Q}

- If you are a lazy developer, would you prefer a weak or a strong precondition {P}?
  + weak {P} ⇒ the starting situation is not constrained
  + strong {P} ⇒ little cases to handle inside the operation
    * The stronger the precondition, the easier it is to satisfy the postcondition
- Easiest Case
  + {false} A {...}
    {false} ⇒ {X} is true for any X
    [because (not {false}) or {X} is always true]
    - if {...} does not hold after executing A, you can blame somebody else because the precondition was not satisfied
    - ... independent of what happens inside A

- **Quiz:** If you are client of that class, would you prefer a weak or strong precondition?

Weak or Strong (Postconditions)

- Given correctness formula: {P} A {Q}

- If you are a lazy developer, would you prefer a weak or a strong postcondition {Q}?
  + weak {Q} ⇒ the final situation is not constrained

  + strong {Q} ⇒ you have to deliver a lot when implementing A

      * The weaker the postcondition, the easier it is to satisfy that postcondition

- Easiest Case
  + {...} A {true}
    {X} ⇒ {true} is true for any X

    [because (not {X}) or {true} is always true]
    - {true} will always hold after executing A
    - ... given that A *terminates* in a finite time

- **Quiz:** If you are client of that class, would you prefer a weak or strong postcondition?

Weak or Strong (Pre- vs. Post-conditions)

- Remember
  + {false} A {...} is easier to satisfy then {...} A {true}
    - With the strong precondition you may go in an infinite loop
    - The weak postcondition must be satisfied in finite time

Invariants

- Invariants correspond to the general clauses in a legal contract, i.e. properties that always must be true for a given domain.

- {I} is an invariant for class C
  + After invoking a constructor of C, {I} is satisfied
    - Default constructors as well!
  + All public operations on C guarantee {I} when their preconditions are satisfied

- Thus, for each operation A defined on class C with invariant {I}
  + {P} A {Q} should be read as {I and P} A {I and Q}
    - strengthens the precondition ⇒ implementing A becomes easier
    - strengthens the postcondition ⇒ implementing A becomes more difficult

Contracts and Inheritance

- `class C with invariant {I}`
  + and operations `{`P_i`}` m_i `{`Q_i`}` where `i: 1 .. n`
- class `C'` extends `C` with invariant `{I'}`
  + and operations `{`P_i`'}` m_i `{`Q_i`'}` where `i: 1 .. n`
- [We ignore the case where C' extends the interface of C]

- Quiz: What's the relationship between the contract in C and the contract in C'
  + Invariant: Is {I'} stronger, weaker or equal to {I}
  + Precondition: Is {P'} stronger, weaker or equal to {P}
  + Postcondition: Is {Q'} stronger, weaker or equal to {Q}

- Answer according to the *Liskov Substitution Principle*
  + *** You may substitute an instance of a subclass for any of its superclasses.

Contracts and Inheritance

- `class C with invariant {I}`
  + and operations `{Pi} mi {Qi}` where `i: 1 .. n`
- class `C'` extends `C` with invariant `{I'}`
  + and operations `{Pi'} mi {Qi'}` where `i: 1 .. n`
- [We ignore the case where C' extends the interface of C]

- Quiz: What's the relationship between the contract in C and the contract in C'
  + Invariant: Is {I'} stronger, weaker or equal to {I}
  + Precondition: Is {P'} stronger, weaker or equal to {P}
  + Postcondition: Is {Q'} stronger, weaker or equal to {Q}

VOTES	stronger	weaker	equal	don't know
{I'} vs. {I}				
{P'} vs. {P}				
{Q'} vs. {Q}				

Sidetrack: ACM Turing Award Barbara Liskov

Press release — NEW YORK, March 10, 2009
– ACM, the Association for Computing Machinery

The ACM has named Barbara Liskov of the Massachusetts Institute of Technology (MIT) the winner of the 2008 ACM A.M. Turing Award. The award cites Liskov for her foundational innovations to designing and building the pervasive computer system designs that power daily life. Her achievements in programming language design have made software more reliable and easier to maintain. They are now the basis of every important programming language since 1975, including Ada, C++, Java, and C#. The Turing Award, widely considered the "Nobel Prize in Computing," is named for the British mathematician Alan M. Turing. The award carries a $250,000 prize, with financial support provided by Intel Corporation and Google Inc.

[…]

In another exceptional contribution, Liskov designed the CLU programming language, an object-oriented language incorporating "clusters" to provide coherent, systematic handling of abstract data types, which are comprised of a set of data and the set of operations that can be performed on the data. She and her colleagues at MIT subsequently developed efficient CLU compiler implementations on several different machines, an important step in demonstrating the practicality of her ideas. Data abstraction is now a generally accepted fundamental method of software engineering that focuses on data rather than processes, often identified as "modular" or "object-oriented" programming.

Liskov substitution principle revisited

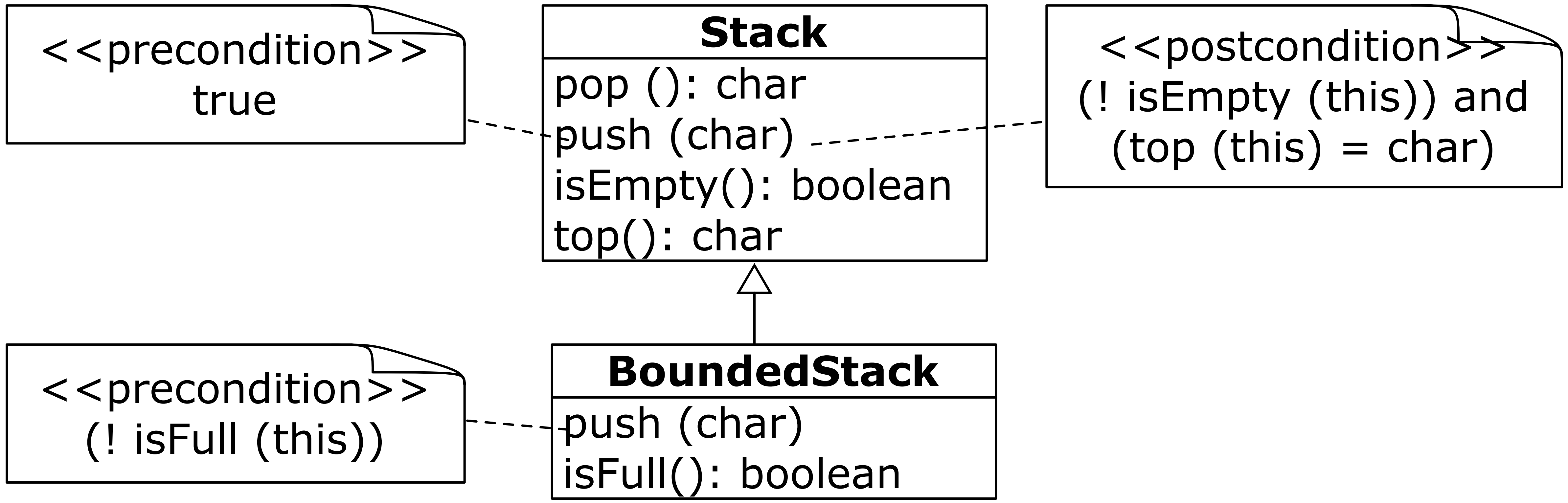
Subtype
Relationship
“is-a”

If it swims like a duck and quacks like a duck, then it’s a duck
(i.e.: the interfaces of the subtype and the supertype are equivalent)

If it swims like a duck and quacks like a duck,
but … needs batteries then it is NOT a duck.

(i.e.: mismatch between the interface of the subtype and the supertype)

Contracts and Inheritance: Example (1/2)



+ A client of Stack assumes a “true” pre-condition on push()
  - Any invocation on push() will deliver the post-condition
+ However, substituting a BoundedStack adds pre-condition
  - “! isFull(this)”
+ BoundedStack requires more from its clients
  - *You cannot substitute a BoundedStack for a Stack*

Contracts and Inheritance: Example (2/2)

As an illustration of the unsatisfied substitution principle, assume the following (test)code

testStack should work for any s: stack we pass !

```
testStack (s: Stack) {
    push(s, 99);
    if empty(s) {
        error(postC)};
    if pop(s) <> 99 {
        error(postC)};
}
```

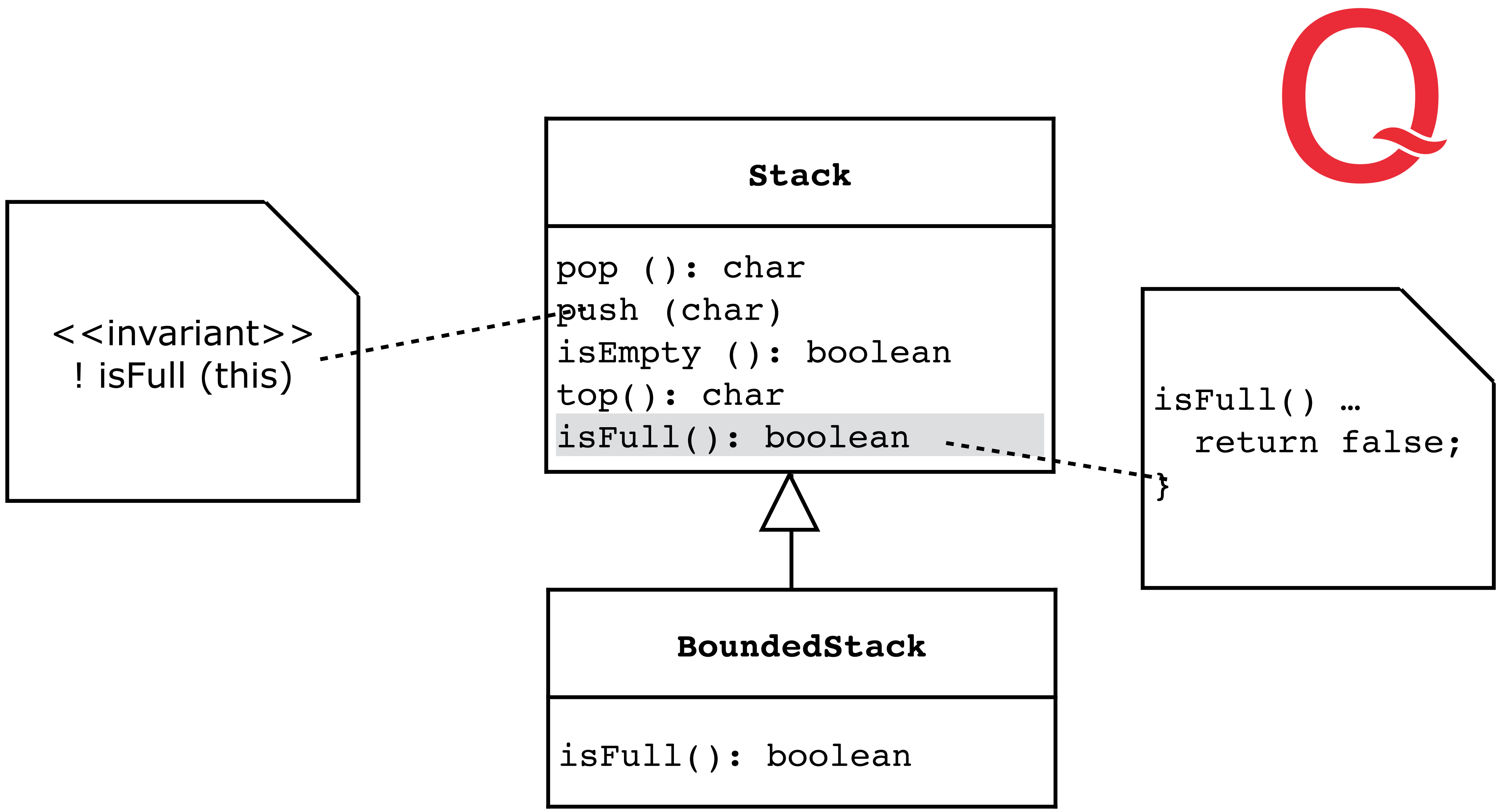
```
BoundedStack s;
s= new BoundedStack(3);
push(s, 1);
push(s, 2);
push(s, 3);
testStack (s);
```

However, it runs into a pre-condition error when we pass a bounded stack that is almost full.

⇒ substitution principle is *not* satisfied

How to fix?

What is the Fix?



- Push the “isFull” method higher and include as pre-condition for all “push” operations
- “isFull” usually returns false, but a BoundedStack overrides

Subclassing and Subcontracting

- Rule
  - + A subclass is a subcontractor of its parent class: it must at least satisfy the same contract

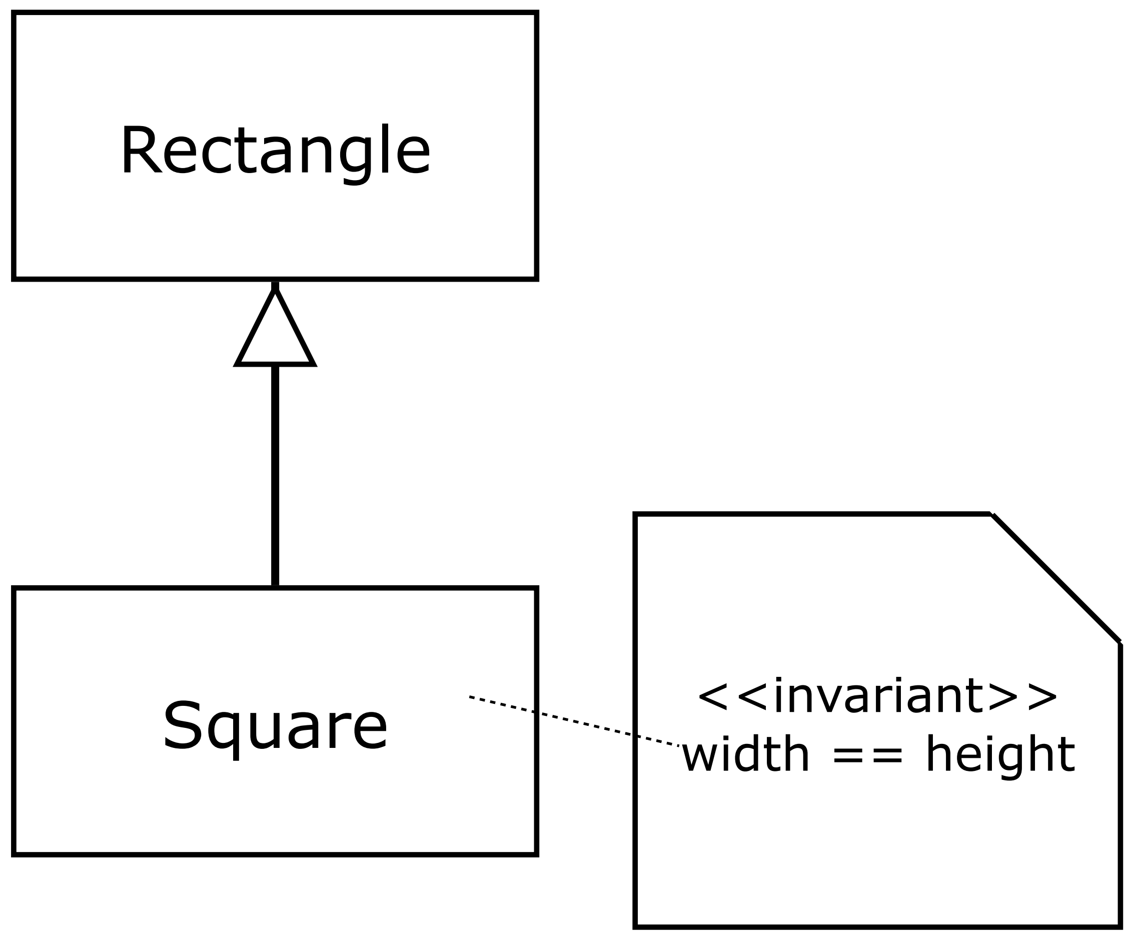
or

  - + If you subcontract, you must be willing to do the job under the original conditions, no less

- Thus
  - + Invariant: {I'} = {I}
    Invariant must remain equal (though may be expressed differently)
  - + Precondition: {P'} is weaker or equal to {P}
  - + Postcondition: {Q'} is stronger or equal to {Q}

- Implementation Issue
  - + Eiffel has special syntax for extensions of pre- and postconditions
    - * Compile-time guarantee that the substitution principle holds
  - + In other languages it is left to the programmer to ensure this rule

Behavioural Subtyping



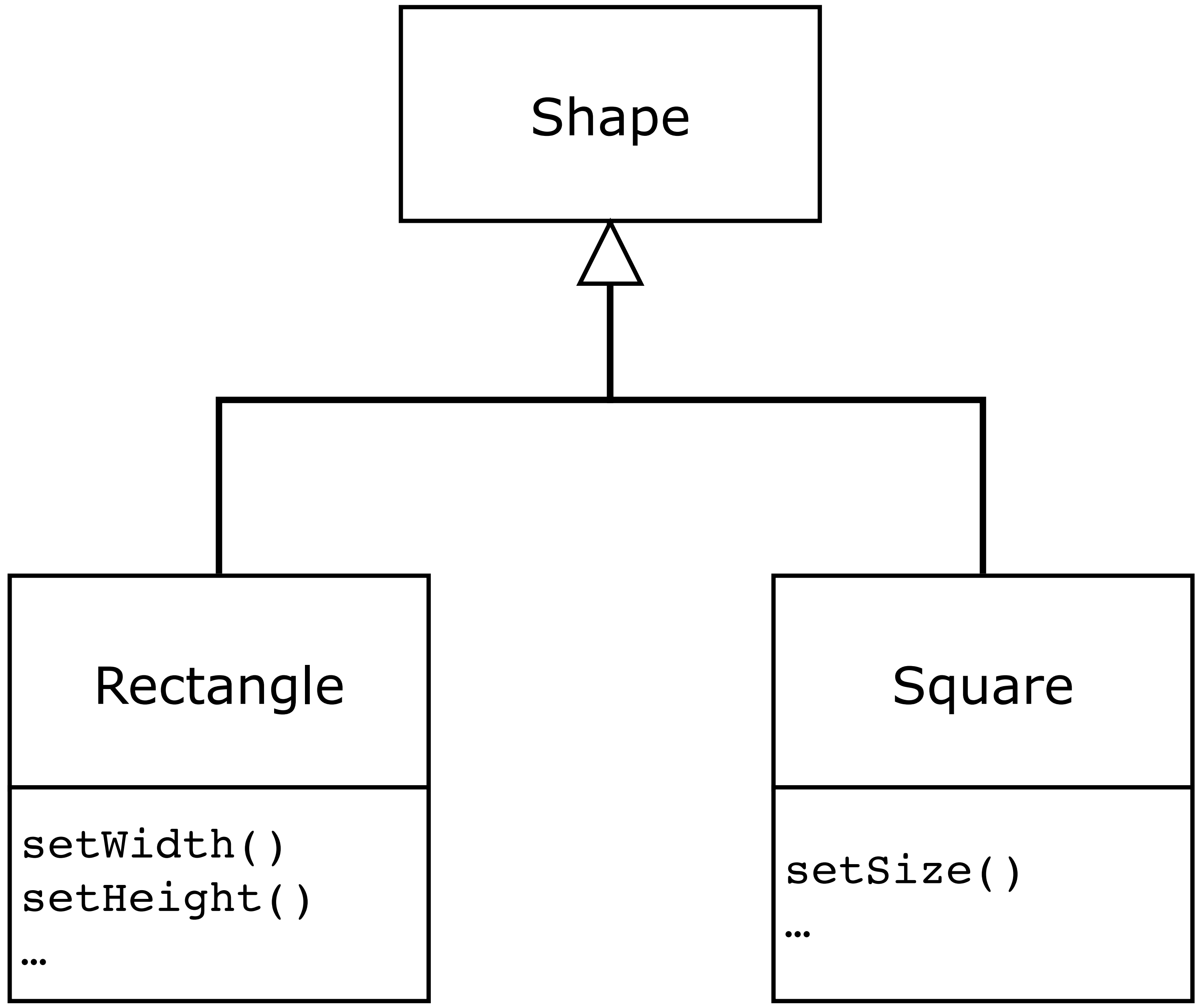
```
testRectangle(Rectangle r) {
  r.setWidth(2);
  r.setHeight(3);
  assert r.getWidth() == 2;
  assert r.getHeight() == 3;
}
```

```
Square s;
s = new Square(3);
testRectangle(s);
```

- a square "is a" rectangle
  - + all square are rectangles; not all rectangles are squares
    - > a square is a *subtype* of a rectangle
- but a square is not a *behavioural subtype* of a rectangle
  - > a square does not respect the contractual obligations of rectangle
  - > rectangle explicitly allows height and width to differ

How to fix?

What is the Fix?



Rectangles and Square become siblings in an inheritance hierarchy

Exam Question

What’s the Liskov substitution principle?
Why is it important in OO development?

Liskov Substitution Principle

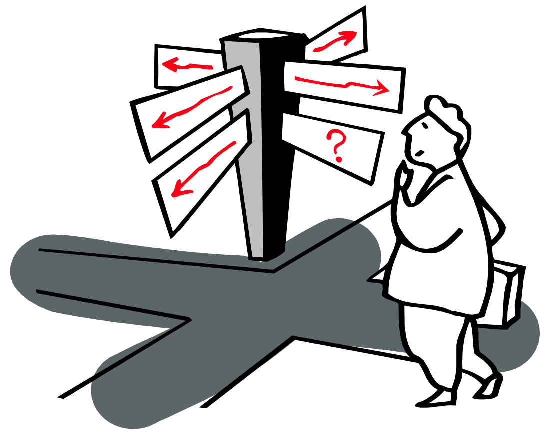
*** You may substitute an instance of a subclass for any of its superclasses.

Why is it Important?

It tells us what a subclass may do with pre- and post-conditions and invariants.

- Invariant: {I’} = {I}
  + Invariant must remain equal (though may be expressed differently)
- Precondition: {P’} is weaker or equal to {P}
- Postcondition: {Q’} is stronger or equal to {Q}

CHAPTER 6 – Design by Contract



- Introduction
  - + When, Why & What
  - + Pre & Postconditions + Invariants
    - - Example: Stack
- Implementation
  - + Redundant Checks vs. Assertions
  - + Exception Handling
  - + Assertions are not…
- Theory
  - + Correctness formula
  - + Weak and Strong
  - + Invariants
  - + Subclassing and Subcontracting
    - - The Liskov Substitution Principle
    - - Behavioral subtyping
- Conclusion
  - + How Detailed?
  - + Tools: The Daikon Invariant Detector
  - + Modern Application: Rest API
  - + Example: Banking
  - + Design by Contract vs. Testing

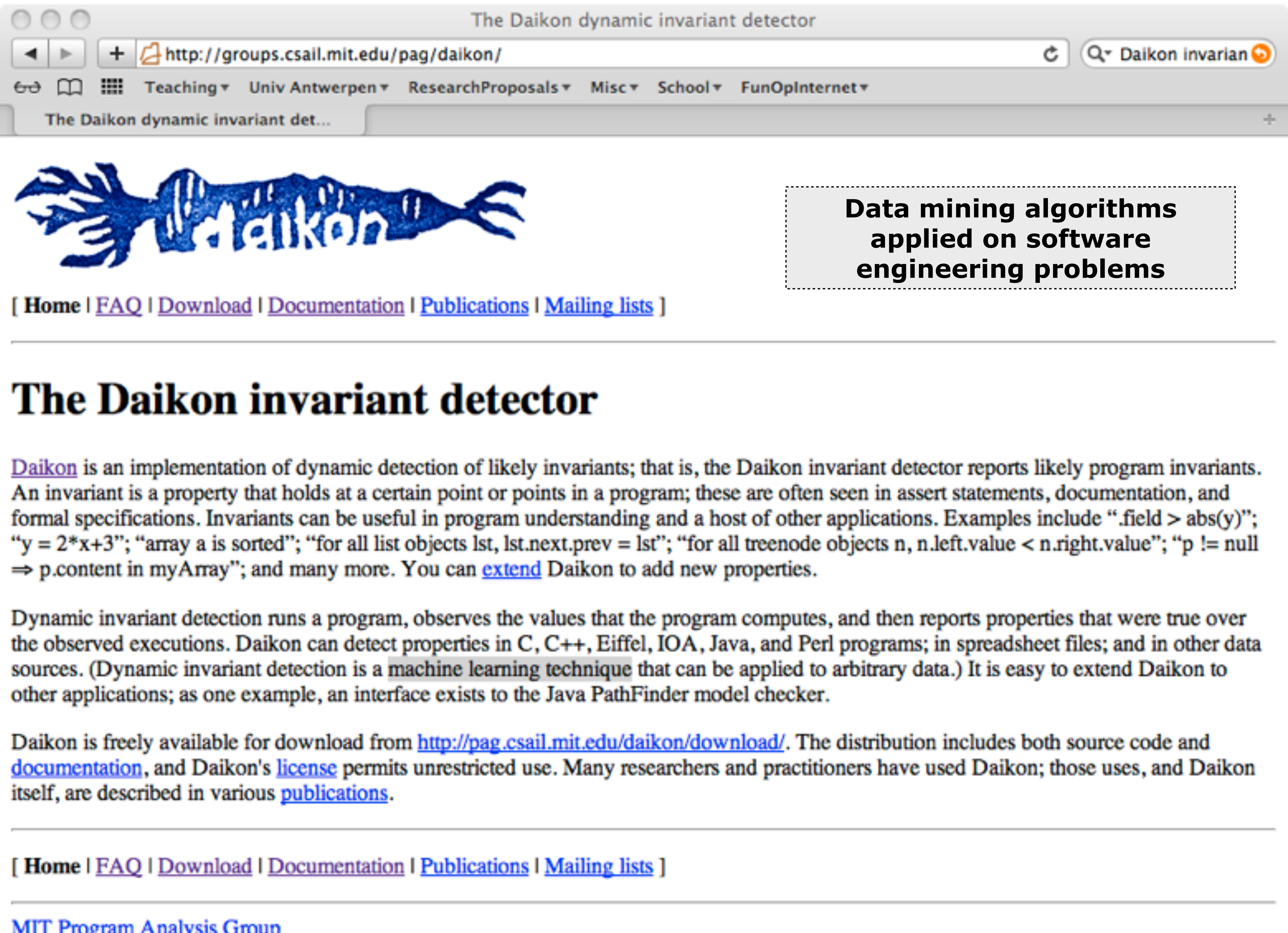
How Detailed Should the Contract Be?

- Given correctness formula: {P} A {Q} for operation A
  + P := {false} is not desirable; nobody will invoke an operation like that
  + P := {true} looks promising... at first sight
    - A will do some computation + check for abnormal cases + take corrective actions and notify clients + produce a result anyway
      * It will be difficult to implement A correctly
      * It will be difficult to reuse A

***** Strong preconditions make a component more reusable**

- Reasonable precondition: When designing a component with preconditions
  + It must be possible to justify the need for the precondition in terms of the requirements specification only
  + Clients should be able to satisfy and check the precondition
    - All operations used inside the precondition should be declared public

cfr. Question on slide — 24. Weak or Strong (Preconditions)
If you are client of that class, would you prefer a weak precondition?
 > *We want a reasonable precondition*


The Daikon dynamic invariant detector
http://groups.csail.mit.edu/pag/daikon/
Daikon invarian
Teaching
Univ Antwerpen
ResearchProposals
Misc
School
FunOpInternet
The Daikon dynamic invariant det...
daikon

Data mining algorithms applied on software engineering problems

[**Home** | FAQ | Download | Documentation | Publications | Mailing lists]

The Daikon invariant detector

Daikon is an implementation of dynamic detection of likely invariants; that is, the Daikon invariant detector reports likely program invariants. An invariant is a property that holds at a certain point or points in a program; these are often seen in assert statements, documentation, and formal specifications. Invariants can be useful in program understanding and a host of other applications. Examples include ".field > abs(y)"; "y = 2*x+3"; "array a is sorted"; "for all list objects lst, lst.next.prev = lst"; "for all treenode objects n, n.left.value < n.right.value"; "p != null ⇒ p.content in myArray"; and many more. You can extend Daikon to add new properties.

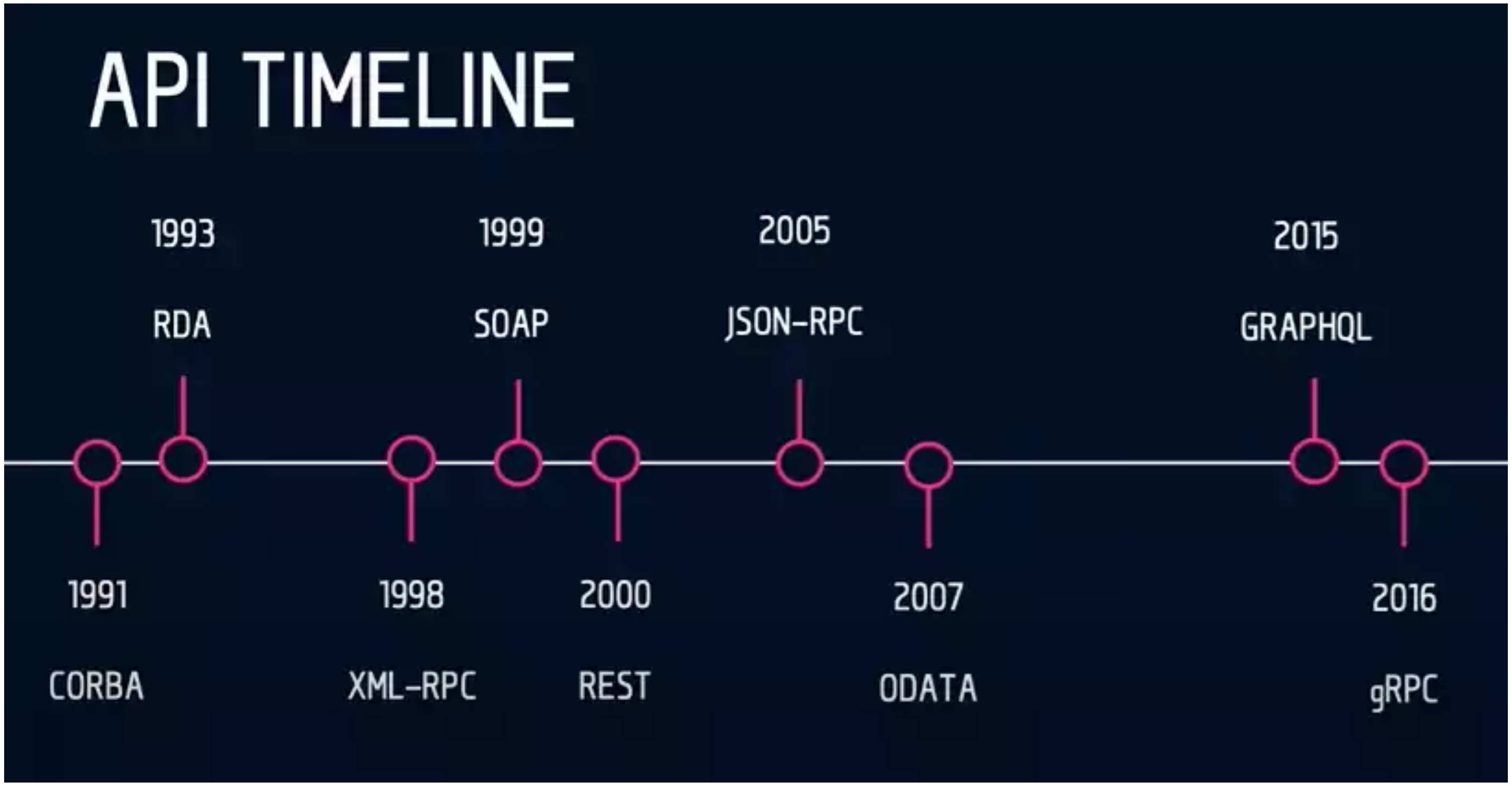
Dynamic invariant detection runs a program, observes the values that the program computes, and then reports properties that were true over the observed executions. Daikon can detect properties in C, C++, Eiffel, IOA, Java, and Perl programs; in spreadsheet files; and in other data sources. (Dynamic invariant detection is a machine learning technique that can be applied to arbitrary data.) It is easy to extend Daikon to other applications; as one example, an interface exists to the Java PathFinder model checker.

Daikon is freely available for download from http://pag.csail.mit.edu/daikon/download/. The distribution includes both source code and documentation, and Daikon's license permits unrestricted use. Many researchers and practitioners have used Daikon; those uses, and Daikon itself, are described in various publications.

[**Home** | FAQ | Download | Documentation | Publications | Mailing lists]

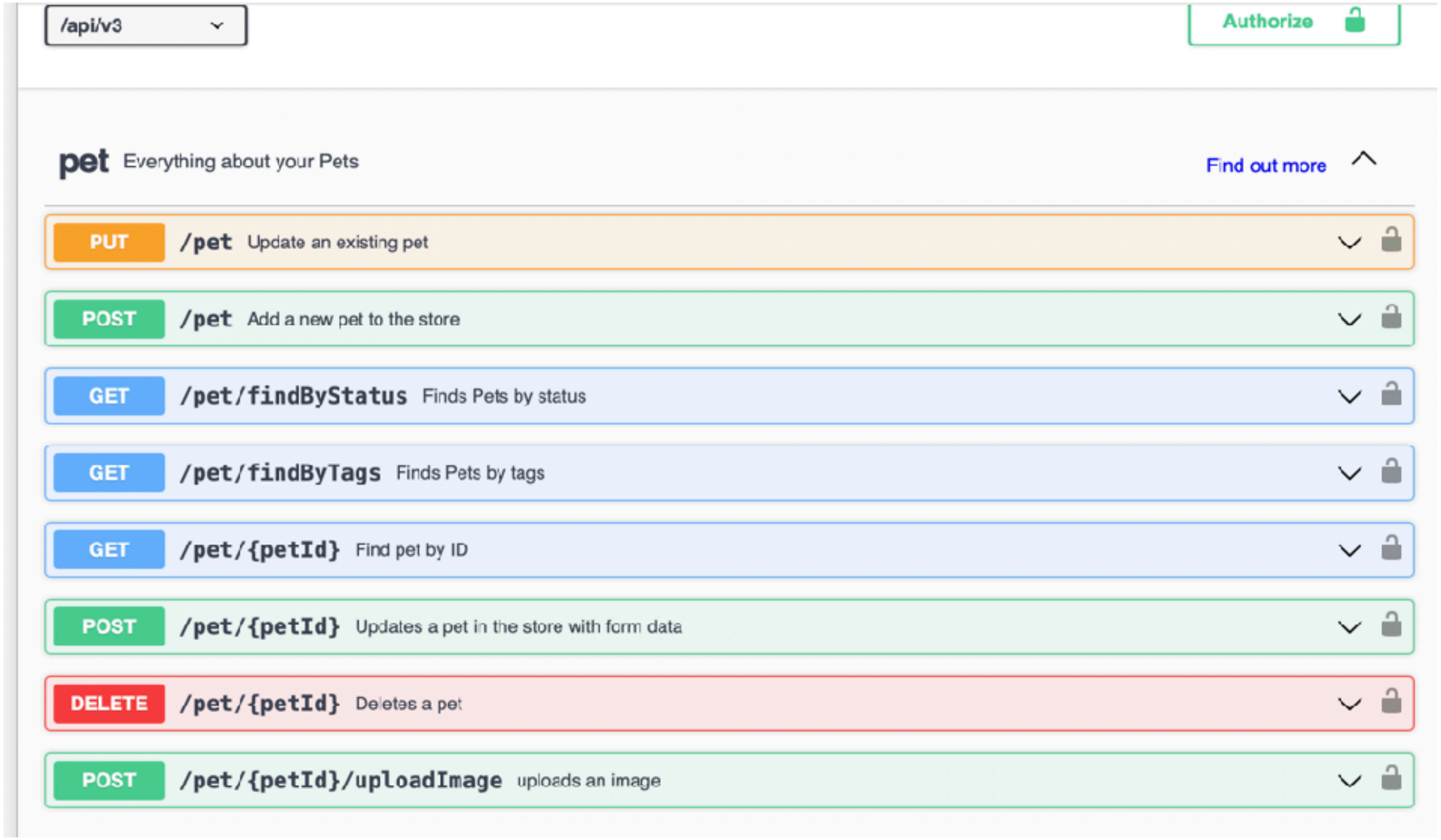
MIT Program Analysis Group

REST API — History



© API styles over time, Source: Rob Crowley

MicroService Example - Pet Store (REST API)


/api/v3

Authorize

pet Everything about your Pets

Find out more

PUT /pet Update an existing pet

POST /pet Add a new pet to the store

GET /pet/findByStatus Finds Pets by status

GET /pet/findByTags Finds Pets by tags

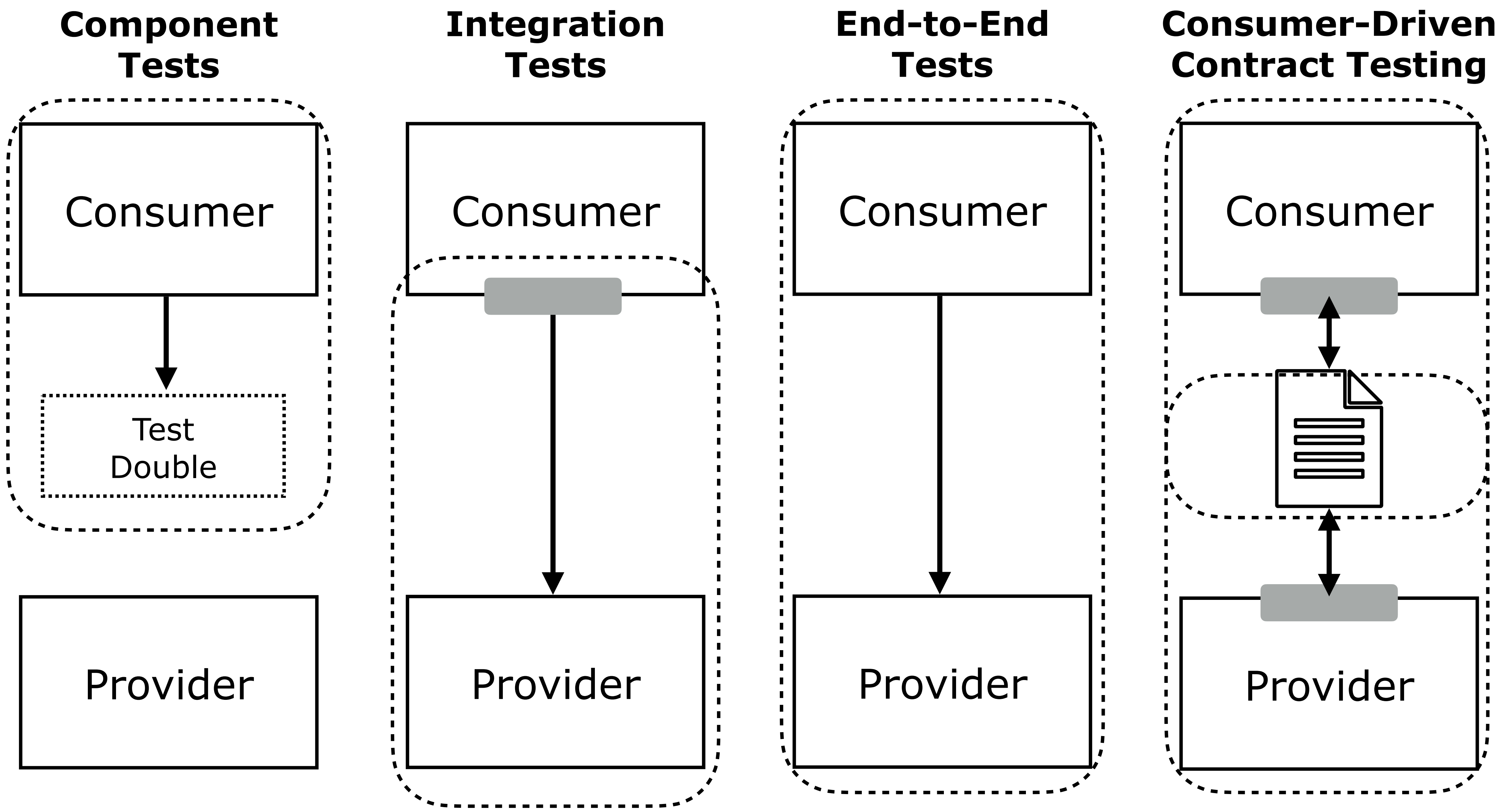
GET /pet/{petId} Find pet by ID

POST /pet/{petId} Updates a pet in the store with form data

DELETE /pet/{petId} Deletes a pet

POST /pet/{petId}/uploadImage uploads an image

Test Strategies for Micro-Services

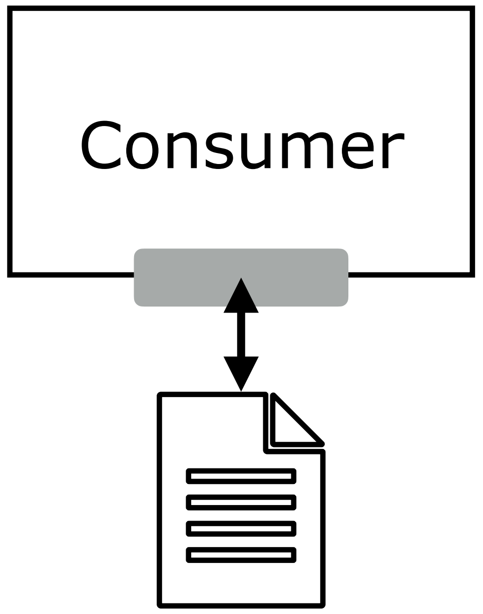


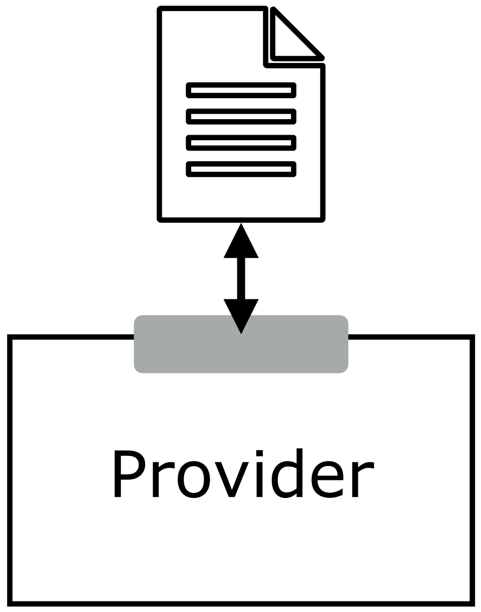
Lehvä, J., Mäkitalo, N., Mikkonen, T. (2019). Consumer-Driven Contract Tests for Microservices: A Case Study. In: Franch, X., Männistö, T., Martínez-Fernández, S. (eds) Product-Focused Software Process Improvement. PROFES 2019. Lecture Notes in Computer Science(), vol 11915. Springer, Cham. https://doi.org/10.1007/978-3-030-35333-9_35

Consumer-Driven Contract Testing

Test micro-services in isolation, solely based on the contractual obligations.

- Consumer
  - + Explicit delivery of the (part of) the contract used.
  - + Mocks the provider based on the (part of the) contract.
- Provider
  - + Replay consumer requests against its API.
  - + Verify responses against contract.





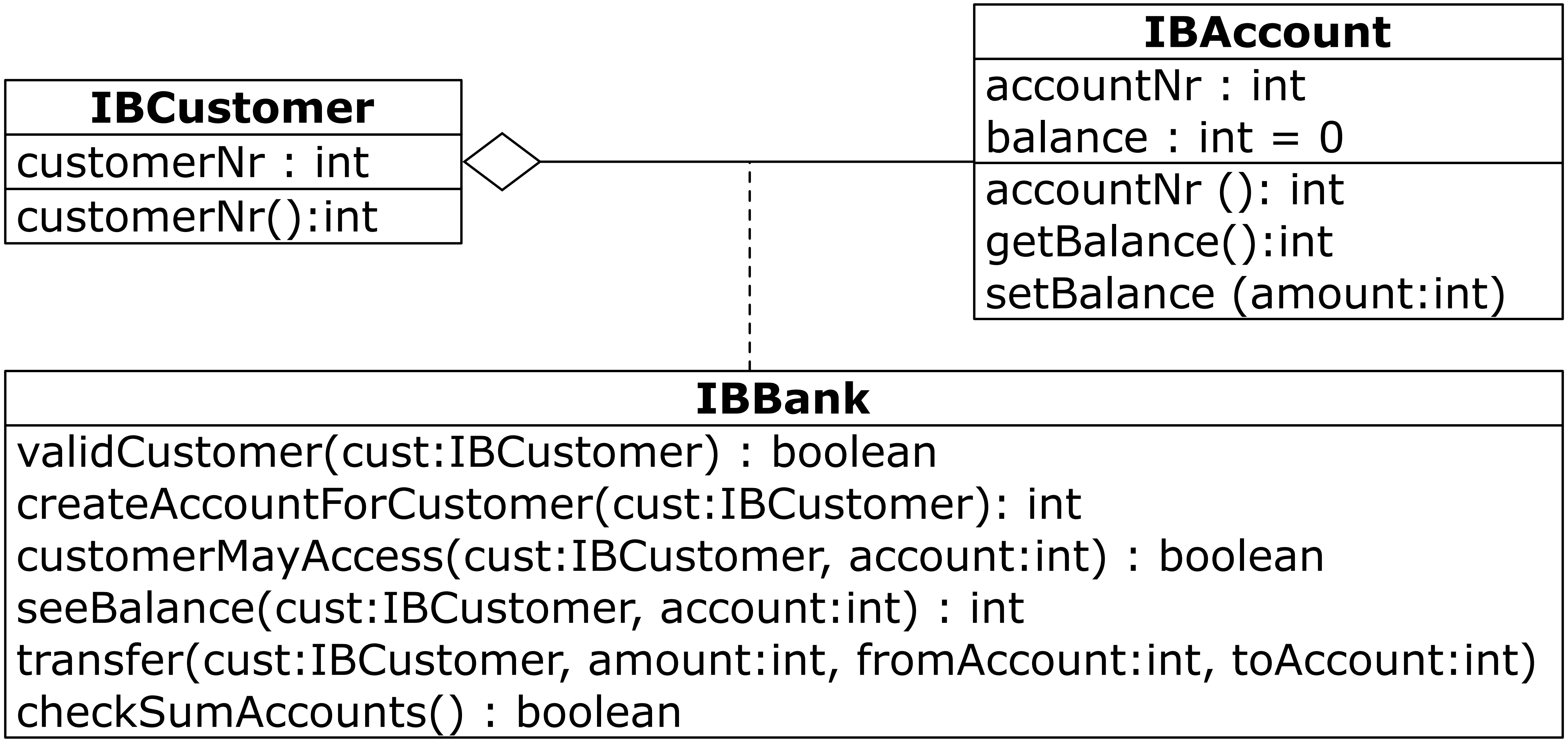
Provider is aware which parts of the contract are actually used by consumers.
> Breaking contracts is explicitly under control.

Example: Banking - Requirements

+ a bank has customers
+ customers own account(s) within a bank
+ with the accounts they own, customers may
    - deposit / withdraw money
    - transfer money
    - see the balance

- Non-functional requirements
  + *secure*: only authorised users may access an account
  + *reliable*: all transactions must maintain consistent state

Example: Banking - Class Diagram


IBCustomer
customerNr : int
customerNr():int
IBAccount
accountNr : int
balance : int = 0
accountNr (): int
getBalance():int
setBalance (amount:int)
IBBank
validCustomer(cust:IBCustomer) : boolean
createAccountForCustomer(cust:IBCustomer): int
customerMayAccess(cust:IBCustomer, account:int) : boolean
seeBalance(cust:IBCustomer, account:int) : int
transfer(cust:IBCustomer, amount:int, fromAccount:int, toAccount:int)
checkSumAccounts() : boolean

Example: Banking - Contracts

Ensure the “secure” and “reliable” requirements.

```
IBBank
    invariant: checkSumAccounts()


IBBank::createAccountForCustomer(cust:IBCustomer): int
    precondition: validCustomer(cust)
    postcondition: customerMayAccess(cust, <<result>>)


IBBank::seeBalance(cust:IBCustomer, account:int) : int
    precondition: (validCustomer(cust)) AND
        (customerMayAccess(cust, account))
    postcondition: true


IBBank::transfer(cust:IBCustomer, amount:int, fromAccount:int, toAccount:int)
    precondition: (validCustomer(cust))
        AND (customerMayAccess(cust, fromAccount))
        AND (customerMayAccess(cust, toAccount))
    postcondition: true
```

Example: Banking - CheckSum

Bookkeeping systems always maintain two extra accounts, “incoming” and “outgoing”

- ⇒ the sum of the amounts of all transactions is always 0 ⇒ consistency check

Incoming

date	amount
1/1/2000	-100
1/2/2000	-200

MyAccount

date	amount
1/1/2000	+100
1/2/2000	+200
1/3/2000	-250

OutGoing

date	amount
1/3/2000	+250

Correctness & Traceability

- Design by contract prevents defects
- Testing detect defects
  + One of them should be sufficient!?

- Design by contract and testing are *complementary*
  + None of the two guarantee correctness ...
    but the sum is more than the parts.
    - Testing *detects* wide range of coding mistakes
    - ... design by contract *prevents* specific mistakes
      (due to incorrect assumptions between provider and client)
  + design by contract ⇒ black box testing techniques
    - especially, equivalence partitioning & boundary value analysis
  + (condition) testing ⇒ verify whether parties satisfy their obligations
    - especially, whether all assertions are satisfied
  + consumer-driven contract testing ⇒ test distributed components in isolation

- Design by contract (and Testing) support Traceability
  + Assertions are a way to record requirements in the source code
  + (Regression) tests map assertions back to the requirements

Summary(i)

- You should know the answers to these questions
  - What is the distinction between Testing and Design by Contract? Why are they complementary techniques?
  - What's the weakest possible condition in logic terms? And the strongest?
  - If you have to implement an operation on a class, would you prefer weak or strong conditions for pre- and postcondition? And what about the class invariant?
  - If a subclass overrides an operation, what is it allowed to do with the pre- and postcondition? And what about the class invariant?
  - Compare Testing and Design by contract using the criteria "Correctness" and "Traceability".
  - What's the Liskov substitution principle? Why is it important in OO development?
  - What is behavioral subtyping?
  - When is a pre-condition reasonable?

- You should be able to complete the following tasks
  - What would be the pre- and post-conditions for the methods top and isEmpty in the Stack specification? How would I extend the contract if I added a method size to the Stack interface?
  - Apply design by contract on a class Rectangle, with operations move() and resize().
  - Write consumer-driven contracts for a given REST-API .

Summary(ii)

- Can you answer the following questions?
  - Why are redundant checks not a good way to support Design by Contract?
  - You're a project manager for a weather forecasting system, where performance is a real issue. Set-up some guidelines concerning assertion monitoring and argue your choice.
  - If you have to buy a class from an outsourcer in India, would you prefer a strong precondition over a weak one? And what about the postcondition?
  - Do you feel that design by contract yields software systems that are defect free? If you do, argue why. If you don't, argue why it is still useful.
  - How can you ensure the quality of the pre- and postconditions?
  - Why is (consumer-driven) contract testing so relevant in the context of micro-services?
  - Assume you have an existing software system and you are a software quality engineer assigned to apply design by contract. How would you start? What would you do?