Will the Real OO Please Stand Up?

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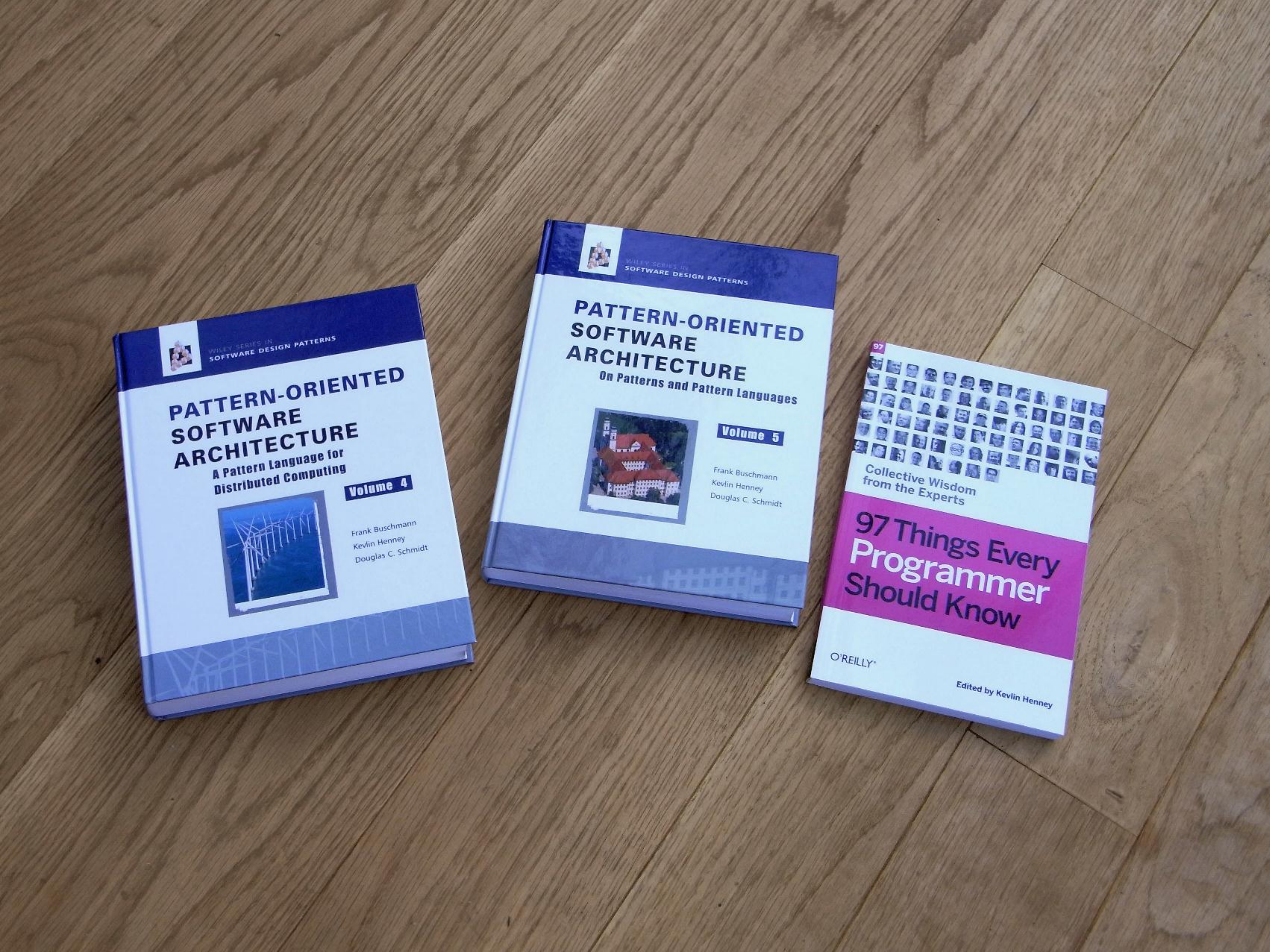
WILEY SERIES IN
SOFTWARE DESIGN PATTERNS
PATTERN-ORIENTED
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A Pattern Language for
Distributed Computing
Volume 4
Frank Buschmann
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97
Collective Wisdom
from the Experts
97 Things Every
Programmer
Should Know
O'REILLY
Edited by Kevlin Henney

The Java programming language platform provides a *portable*, *interpreted*, *high-performance*, *simple*, *object-oriented* programming language and supporting run-time environment.

http://java.sun.com/docs/white/langenv/Intro.doc.html#318

In addition to the facilities provided by C, C++ provides flexible and efficient facilities for defining new types. A programmer can partition an application into manageable pieces by defining new types that closely match the concepts of the application. This technique for program construction is often called *data abstraction*.

Bjarne Stroustrup, *The C++ Programming Language*

OOP to me means only messaging, local retention and protection and hiding of state-process, and extreme late-binding of all things. It can be done in Smalltalk and in LISP. There are possibly other systems in which this is possible, but I'm not aware of them.

Alan Kay

It is possible to do object-oriented programming in Java.

William Cook

It is possible to do object-oriented programming in Java and C# and C++ and...

Ignorance

Apathy

Selfishness

Encapsulation

Inheritance

Polymorphism

Encapsulation

Polymorphism

Inheritance

Encapsulation

Polymorphism

Inheritance

encapsulate *enclose (something) in or as if in a capsule.*

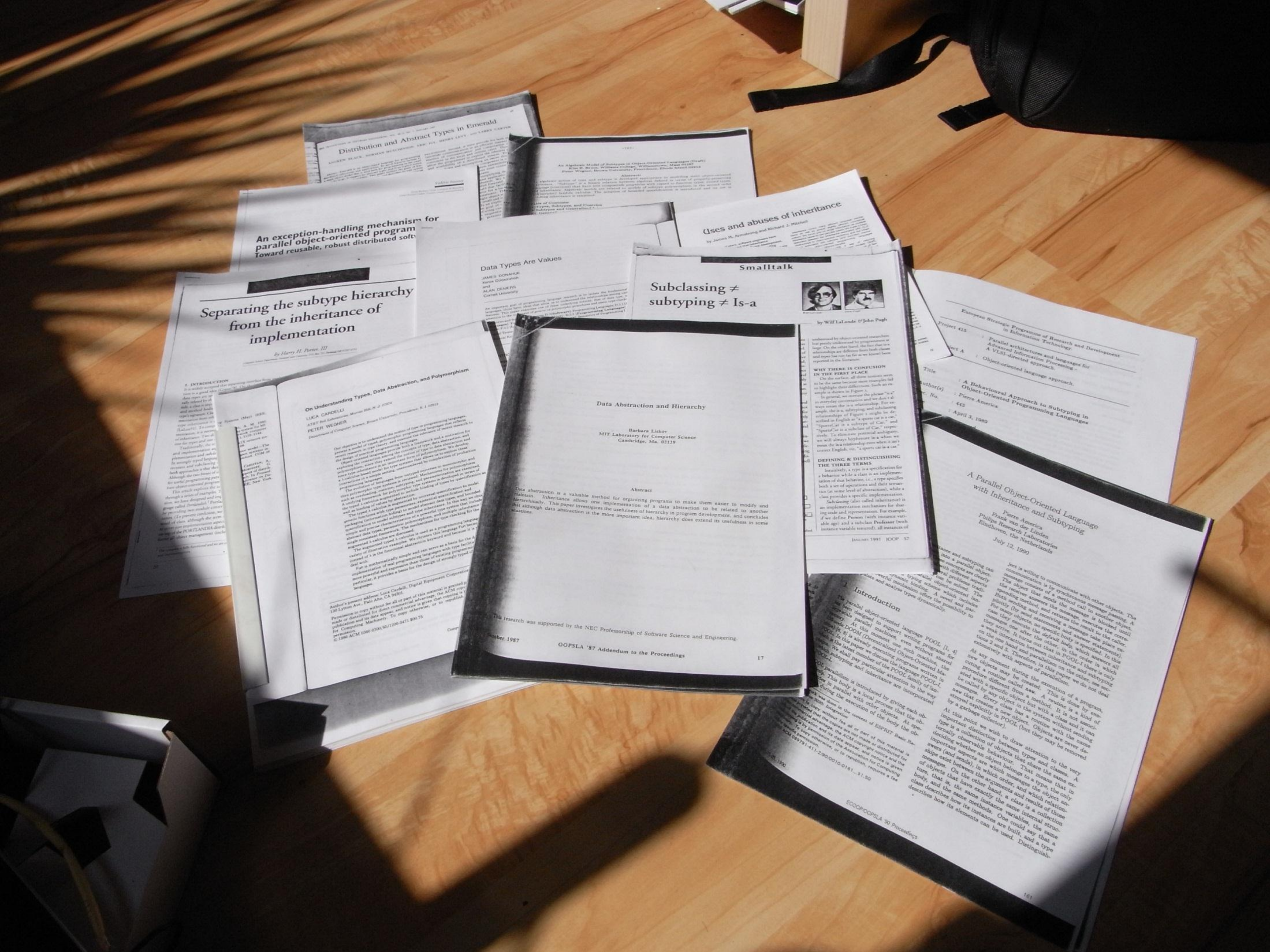
- *express the essential feature of (someone or something) succinctly.*
- *enclose (a message or signal) in a set of codes which allow use by or transfer through different computer systems or networks.*
- *provide an interface for (a piece of software or hardware) to allow or simplify access for the user.*

The New Oxford Dictionary of English

A distinction between inheritance and subtyping is not often made: classes are often equated directly with types. From a behavioural point of view a type defines characteristics and a class defines an implementation of these characteristics.

Kevlin Henney

Distributed Object-Oriented Computing:
The Development and Implementation of an Abstract Machine


Distribution and Abstract Types in Emerald
Uses and abuses of inheritance
Data Types Are Values
JAMES DONAHUE
Xerox Corporation
and
ALAN DEMERS
Cornell University
Smalltalk
Subclassing ≠ subtyping ≠ Is-a
by Wilf LaLonde & John Pugh
Separating the subtype hierarchy from the inheritance of implementation
by Harry H. Porter, III
On Understanding Types, Data Abstraction, and Polymorphism
LUCA CARDELLI
PETER WEGNER
Data Abstraction and Hierarchy
Barbara Liskov
MIT Laboratory for Computer Science
Cambridge, Ma. 02139
Abstract
Data abstraction is a valuable method for organizing programs to make them easier to modify and maintain. Inheritance allows one implementation of a data abstraction to be related to another hierarchically. This paper investigates the usefulness of hierarchy in program development, and concludes that although data abstraction is the more important idea, hierarchy does extend its usefulness in some situations.
This research was supported by the NEC Professorship of Software Science and Engineering.
October 1987
OOPSLA '87 Addendum to the Proceedings
17
European Strategic Programme of Research and Development in Information Technology
A Behavioural Approach to Subtyping in Object-Oriented Programming Languages
Pierre America
April 3, 1989
A Parallel Object-Oriented Language with Inheritance and Subtyping
Pierre America
Frank van der Linden
Philips Research Laboratories
Eindhoven, the Netherlands
July 12, 1990
1 Introduction
ECOOP/OOPSLA '90 Proceedings

In many object-oriented programming languages the concept of *inheritance* is present, which provides a mechanism for sharing code among several classes of objects. Many people even regard inheritance as the hallmark of object-orientedness in programming languages. We do not agree with this view, and argue that the essence of object-oriented programming is the encapsulation of data and operations in objects and the protection of individual objects against each other. [...]

The author considers this principle of protection of objects against each other as the basic and essential characteristic of object-oriented programming. It is a refinement of the technique of abstract data types, because it does not only protect one type of objects against all other types, but one object against all other ones. As a programmer we can consider ourselves at any moment to be sitting in exactly one object and looking at all the other objects from outside.

Pierre America

"A Behavioural Approach to Subtyping in Object-Oriented Programming Languages"

Object-oriented programming does not have an exclusive claim to all these good properties. Systems may be modeled by other paradigms [...]. Resilience can be achieved just as well by organizing programs around abstract data types, independently of taxonomies; in fact, data abstraction alone is sometimes taken as the essence of object orientation.

Martín Abadi and Luca Cardelli
A Theory of Objects

abstraction, *n. (Logic)*

- the process of formulating a generalized concept of a common property by disregarding the differences between a number of particular instances. On such an account, we acquired the concept of *red* by recognizing it as common to, and so abstracting it from the other properties of, those individual objects we were originally taught to call red.
- an operator that forms a class name or predicate from any given expression.

E J Borowski and J M Borwein
Dictionary of Mathematics

$$
\begin{aligned}
&\forall\, T \bullet \exists\, \mathrm{RecentlyUsedList} \bullet \\
&\quad \{ \\
&\qquad \mathrm{new} : \mathrm{RecentlyUsedList}[T], \\
&\qquad \mathrm{isEmpty} : \mathrm{RecentlyUsedList}[T] \to \mathrm{Boolean}, \\
&\qquad \mathrm{size} : \mathrm{RecentlyUsedList}[T] \to \mathrm{Integer}, \\
&\qquad \mathrm{add} : \mathrm{RecentlyUsedList}[T] \times \mathrm{Integer} \to \mathrm{RecentlyUsedList}[T], \\
&\qquad \mathrm{get} : \mathrm{RecentlyUsedList}[T] \times \mathrm{Integer} \to T, \\
&\qquad \mathrm{equals} : \mathrm{RecentlyUsedList}[T] \times \mathrm{RecentlyUsedList}[T] \to \mathrm{Boolean} \\
&\quad \}
\end{aligned}
$$

```
class RecentlyUsedList
{
    private …
    public boolean isEmpty() …
    public int size() …
    public void add(String toAdd) …
    public String get(int index) …
    public boolean equals(RecentlyUsedList other) …
}
```

```
class RecentlyUsedList
{
    private …
    public boolean isEmpty() …
    public int size() …
    public void add(String toAdd) …
    public String get(int index) …
    public boolean equals(RecentlyUsedList other) …
    public boolean equals(Object other) …
}
```

```java
class RecentlyUsedList
{
    private List<String> items = new ArrayList<String>();
    public boolean isEmpty()
    {
        return items.isEmpty();
    }
    public int size()
    {
        return items.size();
    }
    public void add(String toAdd)
    {
        items.remove(toAdd);
        items.add(toAdd);
    }
    public String get(int index)
    {
        return items.get(size() - index - 1);
    }
    public boolean equals(RecentlyUsedList other)
    {
        return other != null && items.equals(other.items);
    }
    public boolean equals(Object other)
    {
        return
            other instanceof RecentlyUsedList &&
            equals((RecentlyUsedList) other);
    }
}
```

```
typedef struct RecentlyUsedList RecentlyUsedList;
```

```
RecentlyUsedList * create();
void destroy(RecentlyUsedList *);
bool isEmpty(const RecentlyUsedList *);
int size(const RecentlyUsedList *);
void add(RecentlyUsedList *, int toAdd);
int get(const RecentlyUsedList *, int index);
bool equals(
  const RecentlyUsedList *, const RecentlyUsedList *);
```

```
struct RecentlyUsedList
{
    int * items;
    int length;
};
```

```
RecentlyUsedList * create()
{
    RecentlyUsedList * result = (RecentlyUsedList *) malloc(sizeof(RecentlyUsedList));
    result->items = 0;
    result->length = 0;
    return result;
}

void destroy(RecentlyUsedList * self)
{
    free(self->items);
    free(self);
}

bool isEmpty(const RecentlyUsedList * self)
{
    return self->length == 0;
}

int size(const RecentlyUsedList * self)
{
    return self->length;
}

static int indexOf(const RecentlyUsedList * self, int toFind)
{
    int result = -1;
    for(int index = 0; result == -1 && index != self->length; ++index)
        if(self->items[index] == toFind)
            result = index;
    return result;
}

static void removeAt(RecentlyUsedList * self, int index)
{
    memmove(&self->items[index], &self->items[index + 1], (self->length - index - 1) * sizeof(int));
    --self->length;
}

void add(RecentlyUsedList * self, int toAdd)
{
    int found = indexOf(self, toAdd);
    if(found != -1)
        removeAt(self, found);
    self->items = (int *) realloc(self->items, (self->length + 1) * sizeof(int));
    self->items[self->length] = toAdd;
    ++self->length;
}

int get(const RecentlyUsedList * self, int index)
{
    return self->items[self->length - index - 1];
}

bool equals(const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
{
    return lhs->length == rhs->length && memcmp(lhs->items, rhs->items, lhs->length * sizeof(int)) == 0;
}
```

```
struct RecentlyUsedList
{
    std::vector<int> items;
};
```

```
extern "C"
{
    RecentlyUsedList * create()
    {
        return new RecentlyUsedList;
    }
    void destroy(RecentlyUsedList * self)
    {
        delete self;
    }
    bool isEmpty(const RecentlyUsedList * self)
    {
        return self->items.empty();
    }
    int size(const RecentlyUsedList * self)
    {
        return self->items.size();
    }
    void add(RecentlyUsedList * self, int toAdd)
    {
        std::vector<int>::iterator found =
            std::find(self->items.begin(), self->items.end(), toAdd);
        if(found != self->items.end())
            self->items.erase(found);
        self->items.push_back(toAdd);
    }
    int get(const RecentlyUsedList * self, int index)
    {
        return self->items[self->items.size() - index - 1];
    }
    bool equals(const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
    {
        return lhs->items == rhs->items;
    }
}
```

OO $\equiv$ ADT?

OO $\not\equiv$ ADT

Autognosis

An object can only access other objects through public interfaces

William Cook, "On Understanding Data Abstraction, Revisited"

```
class RecentlyUsedList
{
    ...
    public boolean equals(RecentlyUsedList other)
    {
        return other != null && items.equals(other.items);
    }
    public boolean equals(Object other)
    {
        return
            other instanceof RecentlyUsedList &&
            equals((RecentlyUsedList) other);
    }
}
```

```
bool equals(const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
{
    return
        lhs->length == rhs->length &&
        memcmp(lhs->items, rhs->items, lhs->length * sizeof(int)) == 0;
}
```

```
extern "C"
{
    ...
    bool equals(const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
    {
        return lhs->items == rhs->items;
    }
}
```

Reflexivity: I am me.

Symmetry: If you're the same as me, I'm the same as you.

Transitivity: If I'm the same as you, and you're the same as them, then I'm the same as them too.

equals

```
public boolean equals(Object obj)
```

Indicates whether some other object is "equal to" this one.

The `equals` method implements an equivalence relation on non-null object references:

- It is *reflexive*: for any non-null reference value `x`, `x.equals(x)` should return `true`.
- It is *symmetric*: for any non-null reference values `x` and `y`, `x.equals(y)` should return `true` if and only if `y.equals(x)` returns `true`.
- It is *transitive*: for any non-null reference values `x`, `y`, and `z`, if `x.equals(y)` returns `true` and `y.equals(z)` returns `true`, then `x.equals(z)` should return `true`.
- It is *consistent*: for any non-null reference values `x` and `y`, multiple invocations of `x.equals(y)` consistently return `true` or consistently return `false`, provided no information used in `equals` comparisons on the objects is modified.
- For any non-null reference value `x`, `x.equals(null)` should return `false`.

Consistency: If there's no change, everything's the same as it ever was.

The `equals` method for class `Object` implements the most discriminating possible equivalence relation on objects; that is, for any non-null reference values `x` and `y`, this method returns `true` if and only if `x` and `y` refer to the same object (`x == y` has the value `true`).

Null inequality: I am not nothing.

Note that it is generally necessary to override the `hashCode` method whenever this method is overridden, so as to maintain the general contract for the `hashCode` method, which states that equal objects must have equal hash codes.

No throw: If you call, I won't hang up.

Hash equality: If we're the same, we both share the same magic numbers.

Here are four common pitfalls that can cause inconsistent behavior when overriding *equals*:

1. Defining *equals* with the wrong signature.
2. Changing *equals* without also changing *hashCode*.
3. Defining *equals* in terms of mutable fields.
4. Failing to define *equals* as an equivalence relation.

Martin Odersky, Lex Spoon and Bill Venners
"How to Write an Equality Method in Java"
http://www.artima.com/lejava/articles/equality.html

Here are four common pitfalls that can cause inconsistent behavior when overriding *equals*:

1. Defining *equals* with the wrong signature.
2. Changing *equals* without also changing *hashCode*.
3. Relying on *equals* and *hashCode* to be invariant when they depend on mutable fields.
4. Failing to define *equals* as an equivalence relation.

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2. Changing *equals* without also changing *hashCode*.
3. Failing to define *equals* as an equivalence relation.
4. Relying on *equals* and *hashCode* to be invariant when they depend on mutable fields.

```
bool equals(
    const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
{
    bool result = size(lhs) == size(rhs);
    for(int index = 0; result && index != size(lhs); ++index)
        result = get(lhs, index) == get(rhs, index);
    return result;
}
```

```
extern "C" bool equals(
    const RecentlyUsedList * lhs, const RecentlyUsedList * rhs)
{
    bool result = size(lhs) == size(rhs);
    for(int index = 0; result && index != size(lhs); ++index)
        result = get(lhs, index) == get(rhs, index);
    return result;
}
```

```
class RecentlyUsedList
{
    ...
    public boolean equals(RecentlyUsedList other)
    {
        boolean result = other != null && size() == other.size();
        for(int index = 0; result && index != size(); ++index)
            result = get(index).equals(other.get(index));
        return result;
    }
    public boolean equals(Object other)
    {
        return
            other instanceof RecentlyUsedList &&
            equals((RecentlyUsedList) other);
    }
}
```

One of the most pure object-oriented programming models yet defined is the Component Object Model (COM). It enforces all of these principles rigorously. Programming in COM is very flexible and powerful as a result. There is no built-in notion of equality. There is no way to determine if an object is an instance of a given class.

William Cook
"On Understanding Data Abstraction, Revisited"

```java
class RecentlyUsedList
{
    ...
    public boolean equals(RecentlyUsedList other)
    {
        boolean result = other != null && size() == other.size();
        for(int index = 0; result && index != size(); ++index)
            result = get(index).equals(other.get(index));
        return result;
    }
    public boolean equals(Object other)
    {
        return
            other instanceof RecentlyUsedList &&
            equals((RecentlyUsedList) other);
    }
}
```

```
class RecentlyUsedList
{
    ...
    public boolean equals(RecentlyUsedList other)
    {
        boolean result = other != null && size() == other.size();
        for(int index = 0; result && index != size(); ++index)
            result = get(index).equals(other.get(index));
        return result;
    }
}
```

In a purist view of object-oriented methodology, dynamic dispatch is the only mechanism for taking advantage of attributes that have been forgotten by subsumption. This position is often taken on abstraction grounds: no knowledge should be obtainable about objects except by invoking their methods. In the purist approach, subsumption provides a simple and effective mechanism for hiding private attributes.

Martín Abadi and Luca Cardelli, *A Theory of Objects*

A type hierarchy is composed of subtypes and supertypes. The intuitive idea of a subtype is one whose objects provide all the behavior of objects of another type (the supertype) plus something extra. What is wanted here is something like the following substitution property: If for each object o1 of type S there is an object o2 of type T such that for all programs P defined in terms of T, the behavior of P is unchanged when o1 is substituted for o2, then S is a subtype of T.

Barbara Liskov
"Data Abstraction and Hierarchy"

It is possible to do Object-Oriented programming in Java

William Cook, "On Understanding Data Abstraction, Revisited"

Object-Oriented subset of Java: class name is <u>only</u> after “new”

William Cook, "On Understanding Data Abstraction, Revisited"

```
interface RecentlyUsedList
{
    boolean isEmpty();
    int size();
    void add(String toAdd);
    String get(int index);
    boolean equals(RecentlyUsedList other);
}
```

```
class RecentlyUsedListImpl
    implements RecentlyUsedList
{
    private List<String> items = …;
    public boolean isEmpty() …
    public int size() …
    public void add(String toAdd) …
    public String get(int index) …
    public boolean equals(RecentlyUsedList other) …
    public boolean equals(Object other) …
}
```

```
class ArrayListBasedRecentlyUsedList
    implements RecentlyUsedList
{
    private List<String> items = …;
    public boolean isEmpty() …
    public int size() …
    public void add(String toAdd) …
    public String get(int index) …
    public boolean equals(RecentlyUsedList other) …
    public boolean equals(Object other) …
}
```

```
class RandomAccessRecentlyUsedList
    implements RecentlyUsedList
{
    private List<String> items = …;
    public boolean isEmpty() …
    public int size() …
    public void add(String toAdd) …
    public String get(int index) …
    public boolean equals(RecentlyUsedList other) …
    public boolean equals(Object other) …
}
```

```
RecentlyUsedList list =
    new RandomAccessRecentlyUsedList();
```

```
class RandomAccessRecentlyUsedList implements RecentlyUsedList
{
    ...
    public boolean equals(RecentlyUsedList other)
    {
        boolean result = other != null && size() == other.size();
        for(int index = 0; result && index != size(); ++index)
            result = get(index).equals(other.get(index));
        return result;
    }
    public boolean equals(Object other)
    {
        return
            other instanceof RecentlyUsedList &&
            equals((RecentlyUsedList) other);
    }
}
```

Here are five common pitfalls that can cause inconsistent behavior when overriding *equals*:

1. Defining *equals* with the wrong signature.
2. Changing *equals* without also changing *hashCode*.
3. Failing to define *equals* as an equivalence relation.
4. Defining *equals* in a class hierarchy where types and classes are not properly distinguished.
5. Relying on *equals* and *hashCode* to be invariant when they depend on mutable fields.


MONOGRAPHS IN COMPUTER SCIENCE
A THEORY OF OBJECTS
MARTÍN ABADI
LUCA CARDELLI
Springer

Lambda-calculus was the first object-oriented language (1941)

William Cook, "On Understanding Data Abstraction, Revisited"

$$
\begin{array}{l}
\mathbf{newRecentlyUsedList} = \\
\quad \lambda \bullet (\mathit{let}\ \mathbf{items} = \mathit{ref}(\langle\rangle) \bullet \\
\quad\quad \{ \\
\quad\quad\quad \mathbf{isEmpty} = \lambda \bullet \#\mathbf{items} = 0, \\
\quad\quad\quad \mathbf{size} = \lambda \bullet \#\mathbf{items}, \\
\quad\quad\quad \mathbf{add} = \lambda\ x \bullet \\
\quad\quad\quad\quad \mathbf{items} := \langle x \rangle \hat{}\ \langle \mathbf{items}_y \mid y \in 0 \ldots \#\mathbf{items} \wedge \mathbf{items}_y \neq x \rangle, \\
\quad\quad\quad \mathbf{get} = \lambda\ i \bullet \mathbf{items}_i \\
\quad\quad \})
\end{array}
$$

```
var newRecentlyUsedList = function() {
    var items = []
    return {
        isEmpty: function() {
            return items.length === 0
        },
        size: function() {
            return items.length
        },
        add: function(newItem) {
            (items = items.filter(function(item) {
                return item !== newItem
            })).unshift(newItem)
        },
        get: function(index) {
            return items[index]
        }
    }
}
```

One of the most powerful mechanisms for program structuring [...] is the block and procedure concept. [...]

A procedure which is capable of giving rise to block instances which survive its call will be known as a *class*; and the instances will be known as *objects* of that class. [...]

A call of a class generates a new object of that class.

Ole-Johan Dahl and C A R Hoare
"Hierarchical Program Structures" in *Structured Programming*

```
var newEmptyRecentlyUsedList = function() {
    return {
        isEmpty: function() {
            return true
        },
        size: function() {
            return 0
        },
        add: function(newItem) {
            var inserted = newInsertedRecentlyUsedList(newItem)
            this.isEmpty = inserted.isEmpty
            this.size = inserted.size
            this.add = inserted.add
            this.get = inserted.get
        },
        get: function(index) {
        }
    }
}
```

```
var newInsertedRecentlyUsedList = function(initialItem) {
    var items = [initialItem]
    return {
        isEmpty: function() {
            return false
        },
        size: function() {
            return items.length
        },
        add: function(newItem) {
            (items = items.filter(function(item) {
                return item !== newItem
            })).unshift(newItem)
        },
        get: function(index) {
            return items[index]
        }
    }
}
```

```
var newRecentlyUsedList = function() {
    var items = []
    return {
        isEmpty: function() {
            return items.length === 0
        },
        size: function() {
            return items.length
        },
        add: function(newItem) {
            (items = items.filter(function(item) {
                return item !== newItem
            })).unshift(newItem)
        },
        get: function(index) {
            return items[index]
        }
    }
}
```

```
var newRecentlyUsedList = function() {
    var items = []
    return {
        ...
        supertypeOf: function(that) {
            return that &&
                that.isEmpty && that.size && that.add &&
                that.get && that.supertypeOf && that.equals
        },
        equals: function(that) {
            var result =
                this.supertypeOf(that) &&
                that.supertypeOf(this) &&
                this.size() === that.size()
            for(var i = 0; result && i !== this.size(); ++i)
                result = this.get(i) === that.get(i)
            return result
        }
    }
}
```

Paradigms lost?

Or paradigms regained?

I believe that the current state of the art of computer programming reflects inadequacies in our stock of paradigms, in our knowledge of existing paradigms, in the way we teach programming paradigms, and in the way our programming languages support, or fail to support, the paradigms of their user communities.

The Paradigms of Programming

Robert W. Floyd
Stanford University

Paradigm(pæ·radim, −dəim) . . . [a. F. *paradigme*, ad. L. *paradigma*, a. Gr. *παραδειγμα* pattern, example, f. *παραδεικνυ·ναι* to exhibit beside, show side by side. . .]
1. A pattern, exemplar, example.
1752 J. Gill *Trinity* v. 91
The archetype, paradigm, exemplar, and idea, according to which all things were made.
From the Oxford English Dictionary.

Today I want to talk about the paradigms of programming, how they affect our success as designers of computer programs, how they should be taught, and how they should be embodied in our programming languages.

A familiar example of a paradigm of programming is the technique of *structured programming*, which appears to be the dominant paradigm in most current treatments of programming methodology. Structured programming, as formulated by Dijkstra [6], Wirth [27, 29], and Parnas [21], among others, consists of two phases.

In the first phase, that of top-down design, or stepwise refinement, the problem is decomposed into a very small number of simpler subproblems. In programming the solution of simultaneous linear equations, say, the first level of decomposition would be into a stage of triangularizing the equations and a following stage of back-substitution in the triangularized system. This gradual decomposition is continued until the subproblems that arise are simple enough to cope with directly. In the simultaneous equation example, the back substitution process would be further decomposed as a backwards iteration of a process which finds and stores the value of the ith variable from the ith equation. Yet further decomposition would yield a fully detailed algorithm.

The venerable master Qc Na was walking with his student, Anton. Hoping to prompt the master into a discussion, Anton said "Master, I have heard that objects are a very good thing — is this true?" Qc Na looked pityingly at his student and replied, "Foolish pupil — objects are merely a poor man's closures."

Chastised, Anton took his leave from his master and returned to his cell, intent on studying closures. He carefully read the entire "Lambda: The Ultimate..." series of papers and its cousins, and implemented a small Scheme interpreter with a closure-based object system. He learned much, and looked forward to informing his master of his progress.

On his next walk with Qc Na, Anton attempted to impress his master by saying "Master, I have diligently studied the matter, and now understand that objects are truly a poor man's closures." Qc Na responded by hitting Anton with his stick, saying "When will you learn? Closures are a poor man's object." At that moment, Anton became enlightened.

http://people.csail.mit.edu/gregs/ll1-discuss-archive-html/msg03277.html