Do general-purpose programming languages have a future?

Bjarne Stroustrup

Texas A&M University

(and AT&T Research)

http://www.research.att.com/~bs

Abstract

As the computing world matures, the roles of computer professionals are becoming more specialized. In particular, a programmer can spend a whole career doing work in embedded systems or data analysis without a need to gain expertise in other fields. Would such programmers be best served by completely different special-purpose languages? What are the fundamental and commercial factors that drive language evolution? What are the roles of program development environments, libraries, and tools? I think that general-purpose languages will have a key role in the programming world, but that the role will evolve and differ from what most people think of today. To make the discussion a bit concrete, I'll base some of my observations on examples from current C++ and its possible future developments.

Intellectual tradition

- My background (think Cambridge and Bell labs)
    - Pragmatic/empirical
        - Build the system the best you can, try it out, measure it, analyze it, fix it, **then** write about it
        - Primarily considers systems to be used by others
    - Idealistic
        - The best system should win
            - Even if it isn’t mine
        - There are usually many different criteria for “best”
            - Individual needs, taste, and opinions matter
        - There are unacceptable ways of winning
            - Lies (incl. gross exaggeration), money, many forms of marketing

My perspective

- Researcher
  - (Ideas and systems can be fascinating by all by themselves)
- Research manager
  - (yes, I can budget; I count costs and estimate economic benefits)
- Consultant
  - (usually unpaid – so I don't have to tell people what they want to hear)
- Teacher
  - (mostly to professional programmers and managers)
- Academic
  - (that's a recent development)

- My bias:
  - Applications with a high systems programming component
  - Industrial applications
  - Software is a very serious business
    - lives depend on software
    - key aspects of our civilization runs on software

Caveat

- My world view is heavily influenced by C++
  - And C++ reflects my world view in many ways
- I don’t consider C++ an ideal language
  - It’s a most useful language (http://www.research.att.com/~bs.applications)
  - I suspect I know its weaknesses as better than most people
    - E.g. irregular syntax and imperfect type system
  - No language is perfect
- I like programming languages
  - I don’t think there could be or should be just one language
  - or just one kind of language
- What we want/need is good software
  - A language is (just) a tool
  - There is no perfect language, and there never will be

Overview

- What is a general-purpose language?
  - And why would anyone care?
- What are the advantages of
  - Special-purpose languages?
  - General-purpose languages?
- Key examples
  - Object model
  - Container models
- Ideals for a general-purpose language
- How might this apply to C++?

Do general-purpose programming languages have a future?”

- For me, this is not just an academic question
  - Should I continue to work on C++?
  - Should I aim for generality?
  - Should I try to guide C++ into a (safe) niche?

  (yes, yes, no)

- In general our answer has implications on
  - how we structure systems
  - what we teach
  - where we spend resources
    - Research
    - Tools

Programming languages

- For every one problem/purpose, the ideal language is a special-purpose one.
  - Examples:
    - Modeling mechanical systems (e.g. car engine, transmission)
    - Stereoscopic display of molecules
    - Engineering math (e.g. symbolic, numeric, visualization)
    - Video game engine (e.g. DOOM)
    - Graphical (e.g. GC)
    - Text manipulation (e.g. layout, analysis, transformation)
    - 2D and 3D Layout (e.g., architectural, chip design, graphics)
    - Graph computation (e.g. routing)
    - Expert systems (e.g. training simulators)
- We can’t always afford our ideals
  - So how can we best approximate them?

What can a language do for a programmer?

- No single language feature is essential
  - Lots of good programs have been written in languages deemed bad
    - C, Cobol, Fortran, …
  - Lots of projects have failed in languages proclaimed great
    - Most failing projects use a fashionable/popular language

- A language cannot
  - Prevent ill-conceived design strategies
  - Prevent ill-conceived implementation strategies

- A language can help a programmer to
  - express concepts directly
  - express independent concepts separately
  - in general
  - affordably

Why do we specialize languages?

- To radically simplify expression of ideas
- To provide stronger guarantees
- To make programming easier for
  - People who are not professional programmers
    - But understand an application domain far better than programmers and computer scientists
  - Novices (students)
    - This can be dangerous
  - The less smart and less highly educated
    - to be able to use more and cheaper programmers (this also can be dangerous)

- When done well, this necessarily limits the area of application

Problems with special-purpose languages

- By definition, an S-P language has an “edge” beyond which a problem cannot be expressed
  - So how do we reason about problems beyond the edge
    - You can’t reason without concepts, without a language
  - How do we extend the S-P language?
    - Modify compiler
    - Add new primitive
    - Link to program fragment written in another language
      - Another S-P language?
      - A low-level language (e.g. C or assembler)
      - A general-purpose language with a suitable library
- Some problems are messy
  - We don’t (yet) have a formal model that could be supported by a special-purpose (domain specific) language

What is a “general-purpose programming language”?

- Originally
  - Without specific restrictions of expressiveness or performance
    - “At least as expressive as Algol 60”
  - Without special facilities and restrictions for commercial or scientific programming
    - Not (just) COBOL
    - Not (just) Fortran
  - PL\1 was the original attempt to unify the programming world
    - Of course it simply added one more faction
      - Once in significant use, a language doesn’t die
    - And it wasn’t better than Fortran and COBOL in their core areas
      - So the special-purpose languages won round #1

Consider application areas
(We’re come a long way since the days of Algol 60)

- Fuel injectors
- Cell phones & systems
- PDAs
- Switching systems
- Games
- Individual business applications
- Database-based transaction systems
- Airspace control systems
- Expert systems
- Symbol manipulation
- Enterprise systems
- Data mining
- Scientific/numeric applications
- Parallel computing
- Missile guidance
- Robotics,
- Telemetry
- Speech recognition/analysis
- Compilers
- Natural language analyzer
- Image processing
- Image analysis
- Medical instrument control
- Payroll systems
- Billing systems
- Airline reservation systems
- Email systems
- Web browsers
- VLSI layout
- Chemical engineering process control
- Device drivers
- Electronic trading
- Engine control
- Graphics
- Geometric modeling,
- Operating systems

What is a “general-purpose programming language”?

- Do we have a general-purpose language?
  - Can a language be consider general-purpose if we can’t use it to write
    - a device driver?
    - an operating system?
    - a text analysis application?
    - a record processing database-intensive application?
    - an expert-system
    - symbolic manipulation application?
    - a web commerce application?
    - an engineering/numeric application?
- We have G-P languages
  - in the sense that we can use them for all such purposes
- We don’t have a G-P language
  - in the sense that a language is a close-to ideal for all such purposes
  - A G-P language is at best the second choice for any one application

What’s right about a G-P language?

- You can do everything in it
  - You can do any two tasks in it
    - And that’s by definition rarely the case for a special-purpose language
  - You can with a high probability collaborate with someone in a different field
    - Share source or link
- But
  - Doing anything without proper libraries is painful
    - Getting libraries from different producers to work together in non-trivial
- A general-purpose language rely on abstraction where special-purpose languages rely on built-in specialized features
  - To improve a general-purpose language, we must strengthen its abstraction mechanisms

There will always be many languages

- Significant systems rely on code written in many languages
- Not just legacy code
  - There are hundreds of millions of lines of code “out there”
  - “legacy code” approximately means “code that’s being used”
- Programmers are often more important than code
  - And programmers differ in their preferences of languages, tools, and programming styles

- A general-purpose language must enable (and preferably encourage and ease) interoperability

Which G-P languages do we currently have?

- Candidates
  - Ada, C, C++, C# (?), Java (?), ML (?), Pascal(?)
  - …
- Not candidates
  - PERL, Visual Basic, Python
  - COBOL, Fortran
  - …
- There are N*1000 languages
  - Domain specific
  - Dead
  - Unsupported
  - Academic
  - Platform specific
  - Proprietary
  - …

Do G-P programming languages have a future?

- Of course, but should they have?
  - yes
- Just for “legacy code”?
  - no
- Would the world be better without them?
  - No, we can’t manage with just special-purpose languages
    - Explorations of new/immature fields
    - Implementation of special-purpose languages
    - As “glue” for special-purpose languages
- Should we try to improve them?
  - Yes, none is anywhere perfect
- What is it about G-P languages that we might improve?
  - Abstraction facilities
  - Interoperability
  - Performance

Can you restrict programming style?

- Type safety is good
  - Not a restriction except when dealing with hardware
  - Complete type safety implies garbage collection
    - for some degree of generality
- Forcing “object orientation” has been a failure
  - “methods” that can’t be overridden
  - “methods” that doesn’t operator on an object
  - Classes have been successful as modules, though
- Strongly condemned features are making a comeback
  - Overloading
  - Generic programming
  - Nested classes / events
  - Multiple inheritance
  - Static type checking
  - Value types

Programming Styles (paradigms)

- A G-P language **will** be used for different paradigms
  - “C style” (“Pascal style”)
    - Procedures, structures, pointers
  - Data abstraction
  - Object-Oriented Programming
  - Generic Programming

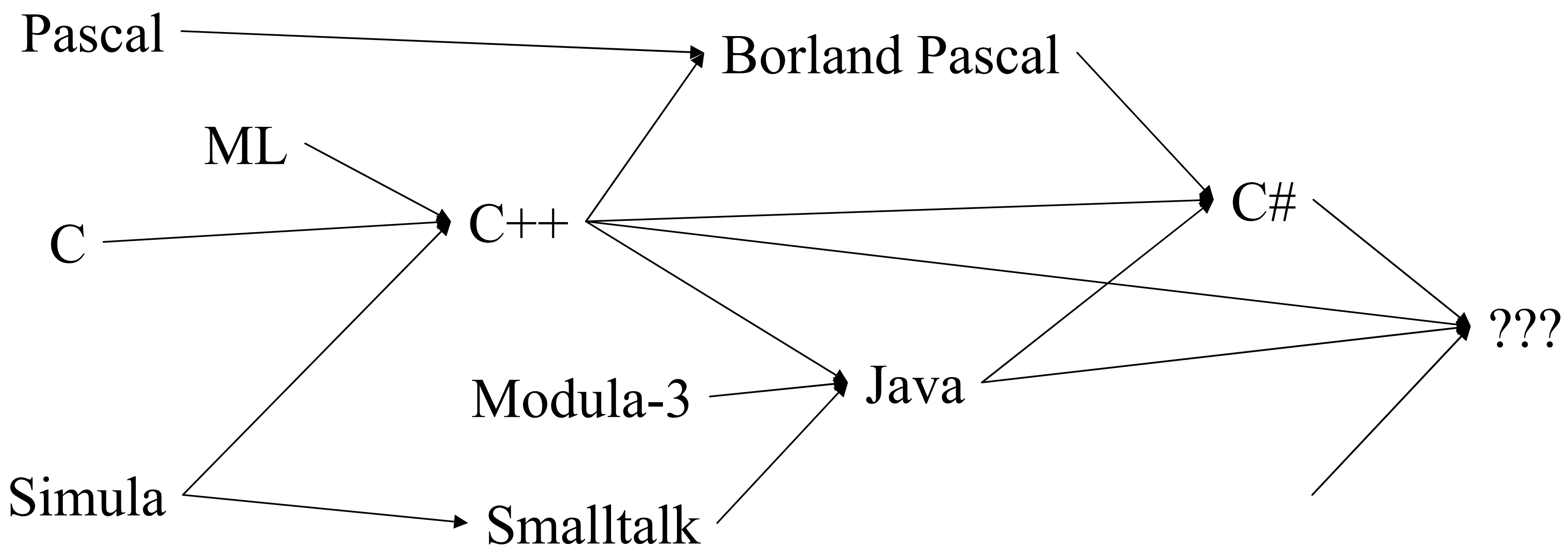
  - Constraints
  - Logical
  - Rule-based
  - Aspect-oriented
  - …
- A general-purpose language needs broad support for paradigms
  - Multi-paradigm programming

Languages “stretch”

- “C++ is a stretch language”
    - - Peter Deutch (it was not meant to be a compliment)

- All languages “stretch” to serve a larger user community
    - By serving A and B you server both A and B better than just serving A or B
    - Need to serve related uses
    - Need to help users meet new challenges
    - Applying lessons of experience
    - Pressure from other languages
- Languages never shrink
    - Older language have many features
        - Some mainly for historical reasons (compatibility)
            - warts
        - Typically offer several ways of doing something
    - All languages are older when they become mainstream

Languages "stretch"



- Classes, inheritance, exceptions, generics, abstract classes, overloading, value types, properties, reflection, type safety, garbage collection, modules, etc.
- **Simplified** chart**:** C, C++, and Java have evolved significantly
- Critical design points:
  - how to handle hardware
  - How to handle performance needs

Is C a G-P Language?

- No
  - It's a low-level language
  - It offers hardly any type safety
  - It offers no advanced features
  - It offers no specific abstraction mechanisms
- Yes
  - It is used for a wider range of applications than any other language
    - Except C++
  - It offers practical portability
  - It runs on essentially every platform
  - It offers performance that allows programmers to compensate for lack of advanced features
  - It interoperates with essentially all languages

Is Java a G-P language?

- No
  - It’s an Object-oriented language ☺
  - It can’t handle low-level systems programming
  - It can’t handle high-performance computing
  - It’s strengths comes partly from restriction
  - It’s a platform
    - Give up portability and you can handle a wider range of applications
- Yes
  - It can do more than Algol60 ☺
  - It can handle an huge range of applications “well enough”
- It is becoming a stretch language
  - Several “editions” to increase its range of underlying systems
    - At the cost of portability
  - Many new language features over the years

Is it fair to consider performance?

- Yes, performance often matters
  - Commerce: amazon, google, Amadeus, …
  - Images: medical, movies, games, …
  - Gadgets: cell phones, fuel injectors, …
  - Scientific computation: protein folding, heat transfer, weather forecasting, …
  - Data management: mining, data capture, real time analysis (e.g. fraud detection, monitoring), DBMS, …
- Naturally, performance isn't always important
  - Often, it is not
  - But I can see echo delays in some modern single-user text processing systems running on a GHz machine
    - (I consider that a disgrace)

A general-purpose language must efficient

- In time
- In space
- Where needed
- Predictably
- Portably

(this is a very tough challenge)

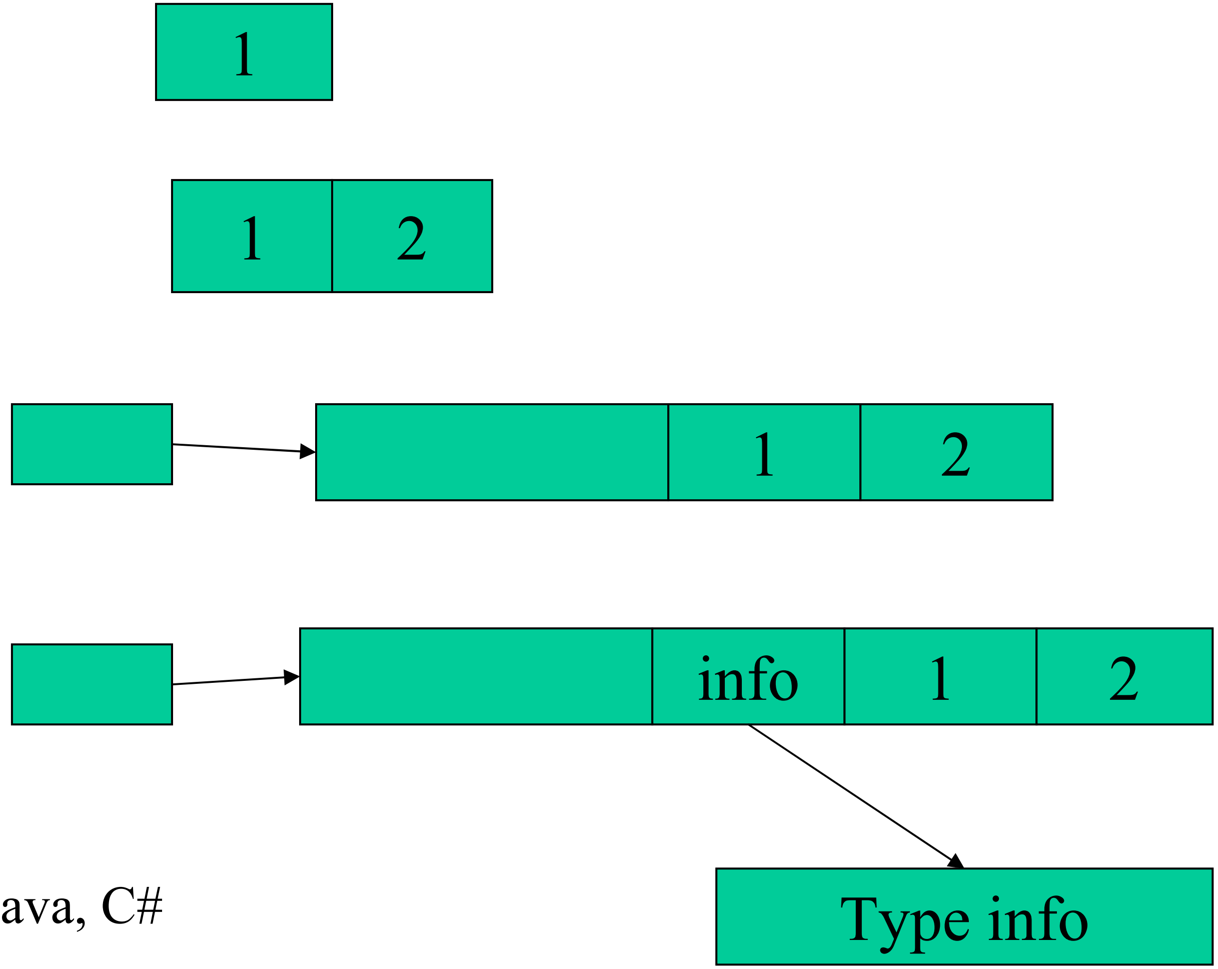
Object models

Primitive object

Composite object

Object on heap

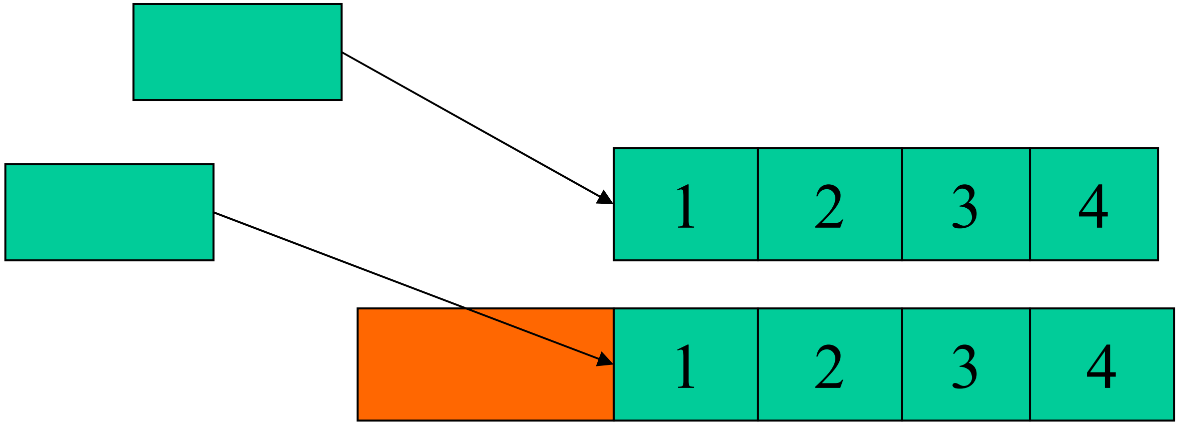
Polymorphic object



- Consider
  - Fortran, C, C++, Java, C#
  - Interoperability
  - Hardware access

Object model – C “container”

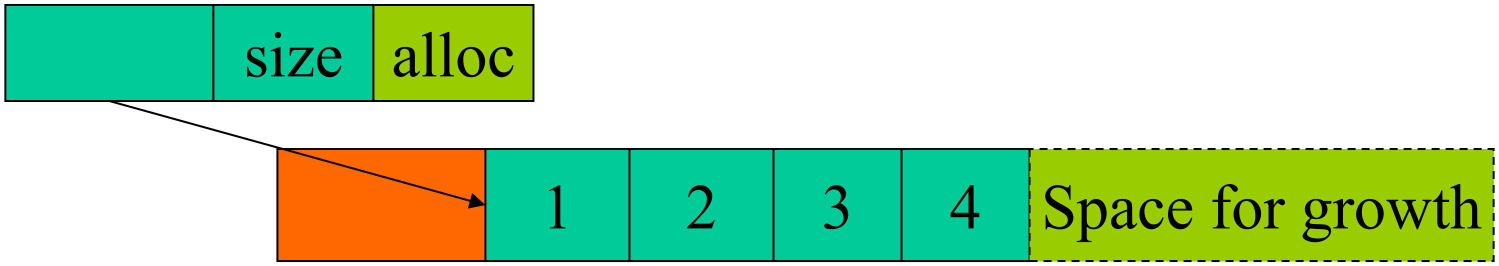
```
struct Cmplx { double re, im; };
struct Cmplx a[MAX] ;
struct Cmplx *p = a;
Struct Cmplx *q = malloc(sizeof(struct Cmplx)*MAX);
```



- Can address specific hardware locations directly
  - bytes, half-words, words, double words, etc.
- Can match externally imposed layout exactly (bit fields)
- Explicit management of heap (2 words per array overhead)

Object model – C++ container

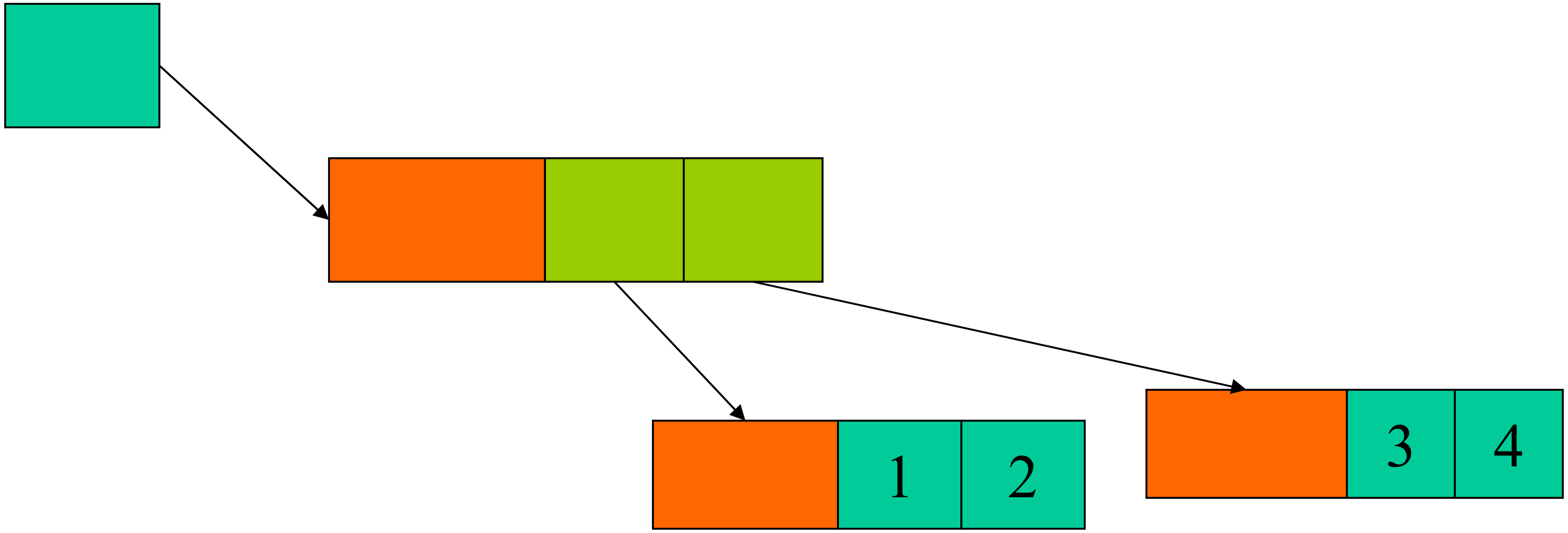
class complex { double re, im; public: /* operations and operators */ **};**
vector<complex> v;



- Like C plus abstraction
  - Enables, but doesn't require run-time range checking
- User-defined types are fundamentally similar to built-in types
- 4 words per vector overhead

Object model – Java/C# container

class Complex { double re, im; /* operations and operators */ **};**
Complex[] v = new Complex[2];
v[0] = new Complex(1,2);



- References plus data on (garbage collected) heap
- Built-in types differ from user-defined types
- 2 words per vector plus 2 words per element overhead

Key example: Container access

- Most basic: C array
  - (support for contiguous sequence of element of built-in types; that’s what traditional hardware supports)

```
int a[4];              // holds objects directly
a[2] = 7;
int x = a[2];

struct My_type p = 0;
void* aa[4];           // indirection needed for polymorphism
aa[2] = p;
p = (struct My_type*) aa[2];          // explicit, efficient, and
                                      // unchecked conversion (unsafe)
```

Key example: Container access

- Container of general (“universal”) object
  - Java, C#, (and C++ if you really want to)

```
int[] a = new int[10];   // special case for Array and small built-in types
a[5] = 5;
int x = a[5];

ArrayList aa = new ArrayList(10); // container of references to objects
aa[5] = new My_class(3);
My_class v = (My_class)aa[5];       // explicit run-time check
```

  - That cast is ugly, expensive, and often logically unnecessary

Key example: Container access

- Typed container
  - C++ (and soon Java and C#)

    ```
    // no special case for small built-in types (in C++ at least)
    Vector<My_class> vmc[10];        // state the element type explicitly
    vmc[5] = My_class(3);
    My_class v = vmc[5];
    ```

  - C++
    - no run-time test
    - elements are access directly (store pointer if you want indirection)
  - C#, Java:
    - implicit (expensive) run-time test
    - elements are still stored indirectly

Roles for a general-purpose language

- Language for writing libraries
- Language for writing messy application parts
- Language for writing performance critical application parts
- Target for code generation
- Low-level glue language (e.g. C, unsafe, fast)
  - As opposed to scripting languages
- Higher-level glue language (e.g. Java, safe, slow)
- Language for writing complete applications (?)
  - Only through libraries, increasingly through libraries
- Teaching language (?)
  - It is much easier to teach a simplified language
  - Where, when, and how do you learn about real-world problems and constraints?

Can a general-purpose language be completely type safe?

- Depends on your definition
  - Strictly-speaking: No
  - But complete type safety is an advantage for a **huge** range of uses
  - Probably unfair to deem a language that has a large stretch “not general-purpose”
- We need to improve interoperability between type safe and (typically unsafe) low-level languages
  - Verification/proof techniques
  - Clear (and non-proprietary) interfaces
  - Clearly declared unsafe program areas (like Modula-3)
  - …

Ideals for a G-P language

- Simplicity
  - Incl. teachability
- Precise specification
- Easy to analyze
- Run-time performance
  - uncompromising
- Ability to run everywhere
  - And take advantage of local facilities
- Type safety
  - And a facility to do type-unsafe operations
- Extensibility
  - Good abstraction facilities
- Ability to interoperate
  - With code from different implementations
  - With code from different languages

Can any of this be used to improve C++?

- C++0x is being prepared by the ISO C++ committee
  - Plus national representatives, of course
  - Design by committee is a horror
    - Committees don’t have an overall aim/”vision”
    - (some) Individuals do (and they don’t agree)
    - Compromises are needed
      - “a language good enough for everyone and ideal for none”
  - Only a committee can deal with an established mainstream language
    - “the ISO committee process is the worst, except for all the alternatives” (with apologies to W. Churchill)

Overall Goals

- Make C++ a better language for systems programming and library building
  - Rather than providing specialized facilities for a particular sub-community (e.g. numeric computation or Windows application development)
  - Maintain the zero-overhead principle
- Make C++ easier to teach and learn
  - Through increased uniformity, stronger guarantees, and facilities supportive of novices (there will always be more novices than experts)
  - Through better libraries

So,
do general-purpose programming languages have a future?

- Yes
  - And we still have a long way to go to meet obvious ideals
    - Type safety
    - Elegant and general abstraction
    - Performance
    - Interoperability
    - Teachability
    - Regular syntax and semantics
  - Look to C, C++, C#, Java
    - That’s where the major use that shapes demands will be
    - Ideas can come from experimental languages