Concept Programming

The Art of Turning Ideas into Code

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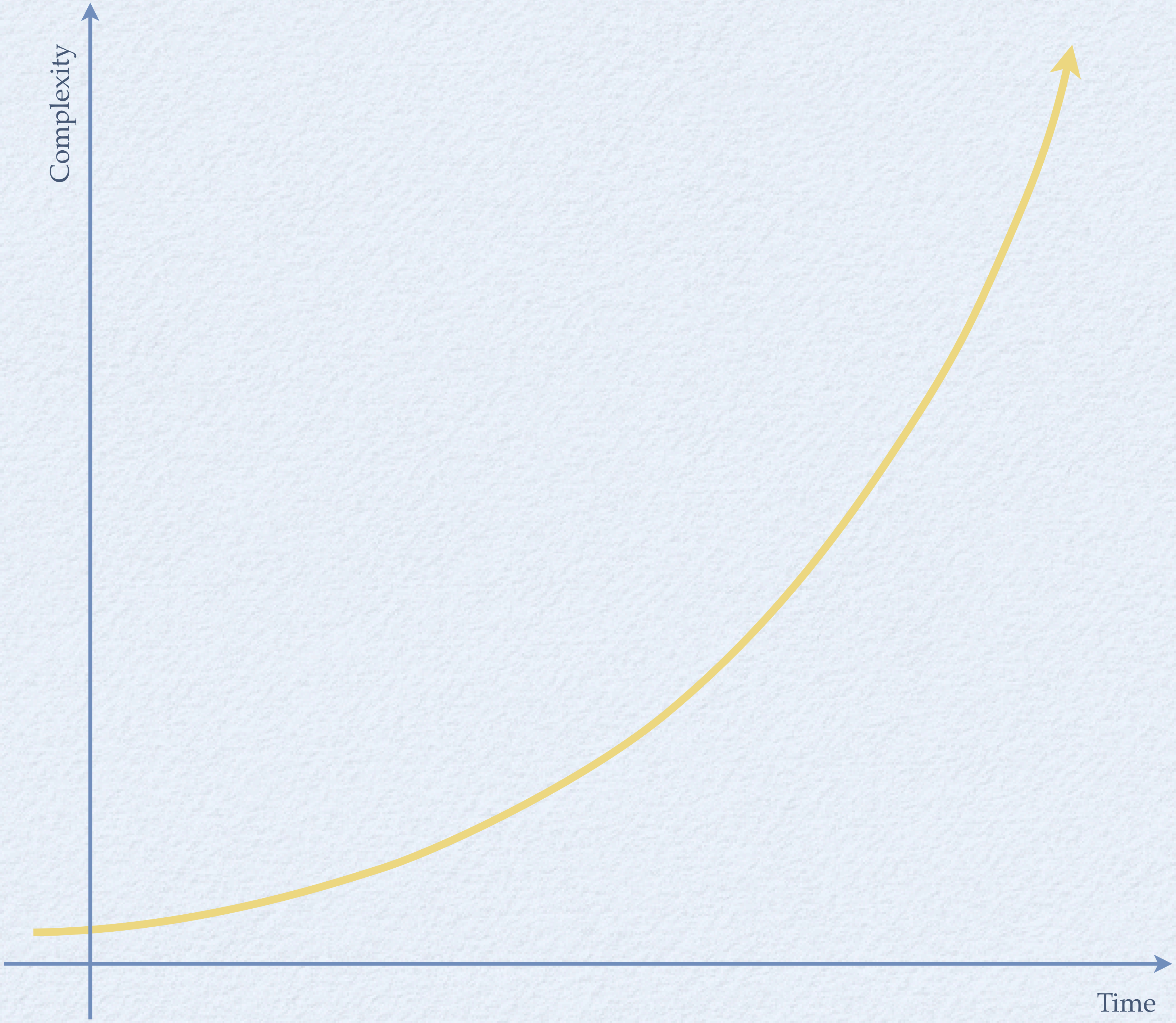
Problem statement

Dealing with Ever Increasing Software Complexity

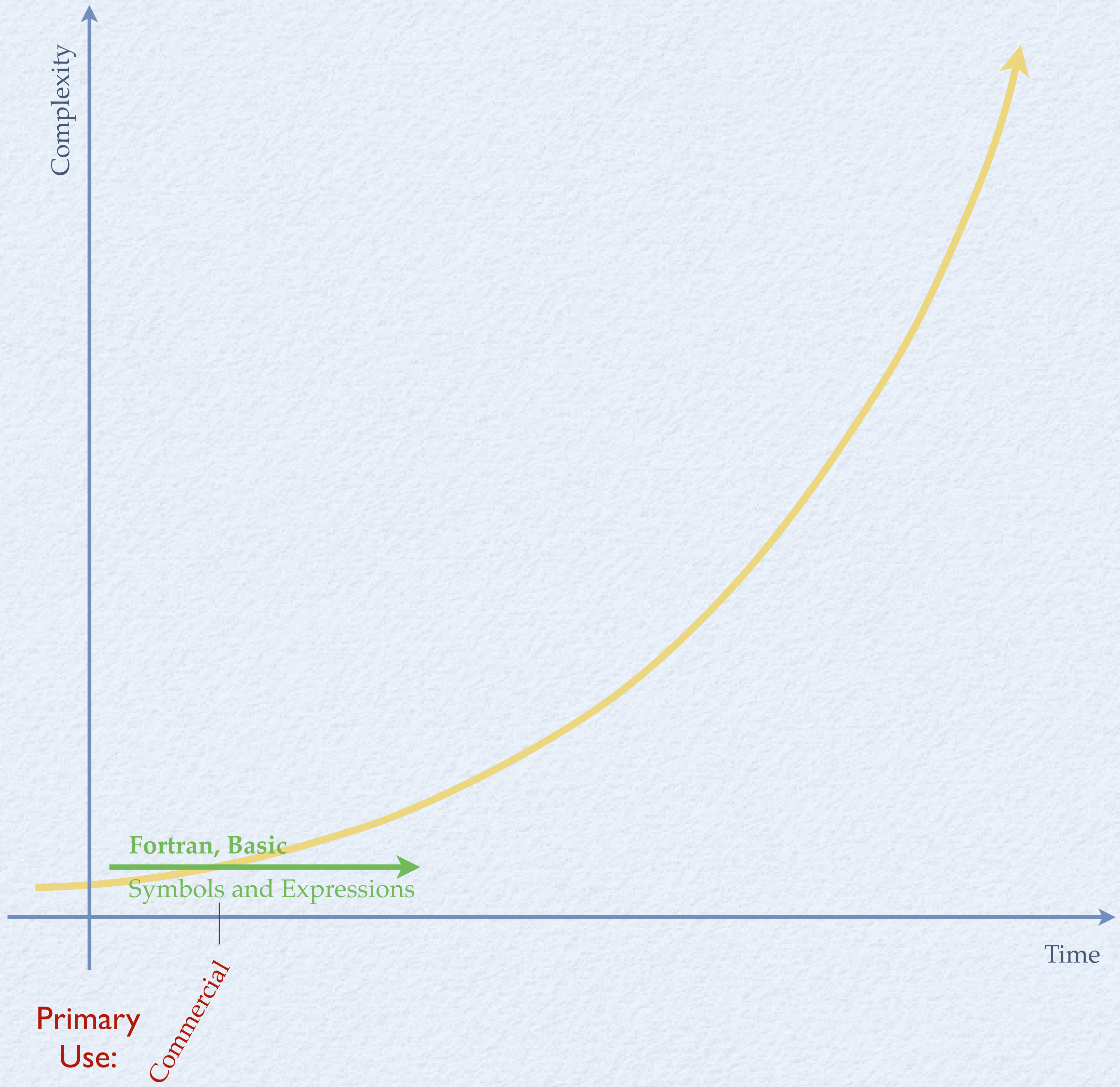
Exponential Growth



Primary Use:

- Software complexity follows Moore's law
- Driven by customers, not by programmers
- Programmers brains can't keep up
- Result: periodic paradigm shifts...
- ... obsoleting all the legacy

Exponential Growth



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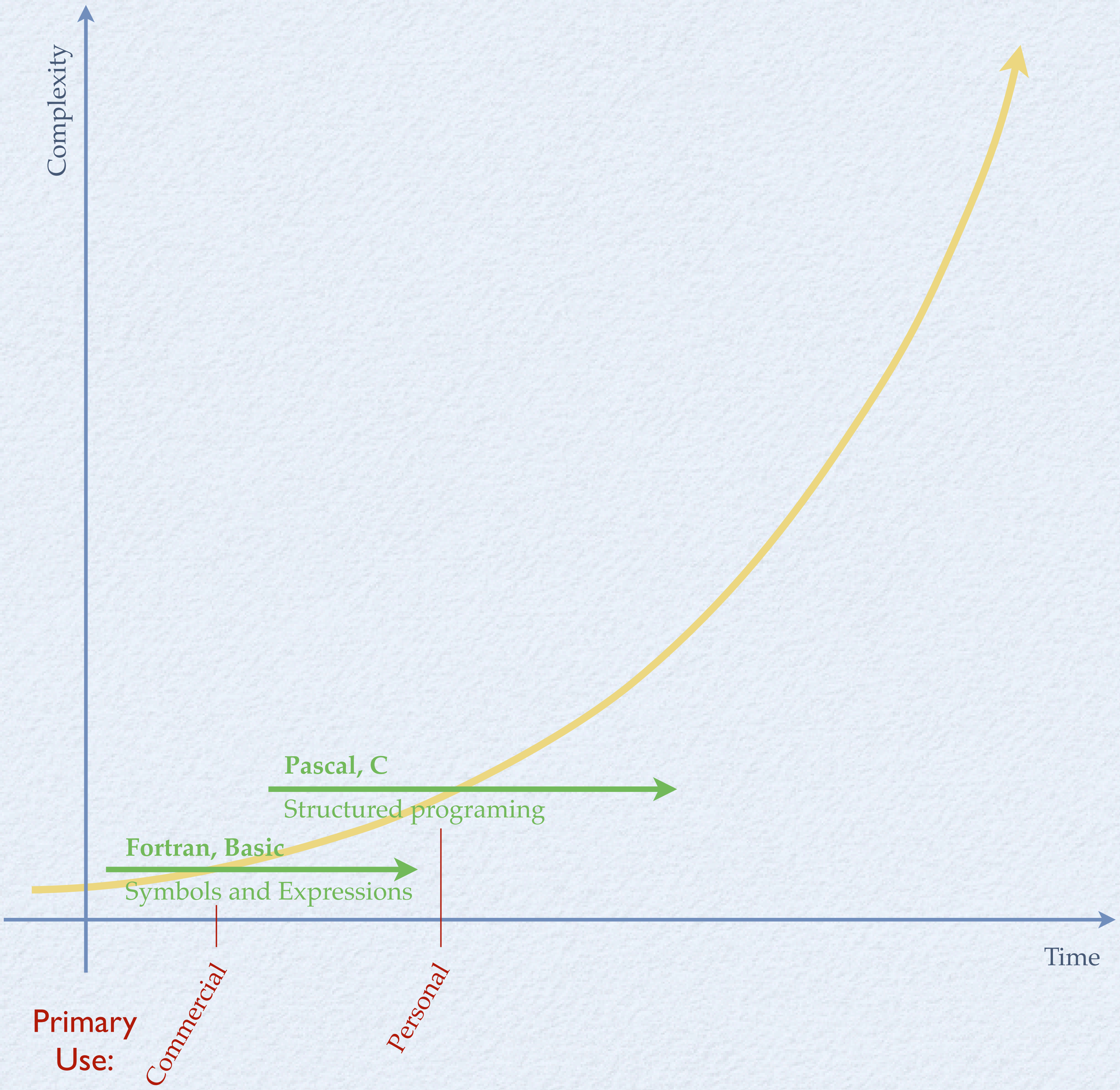

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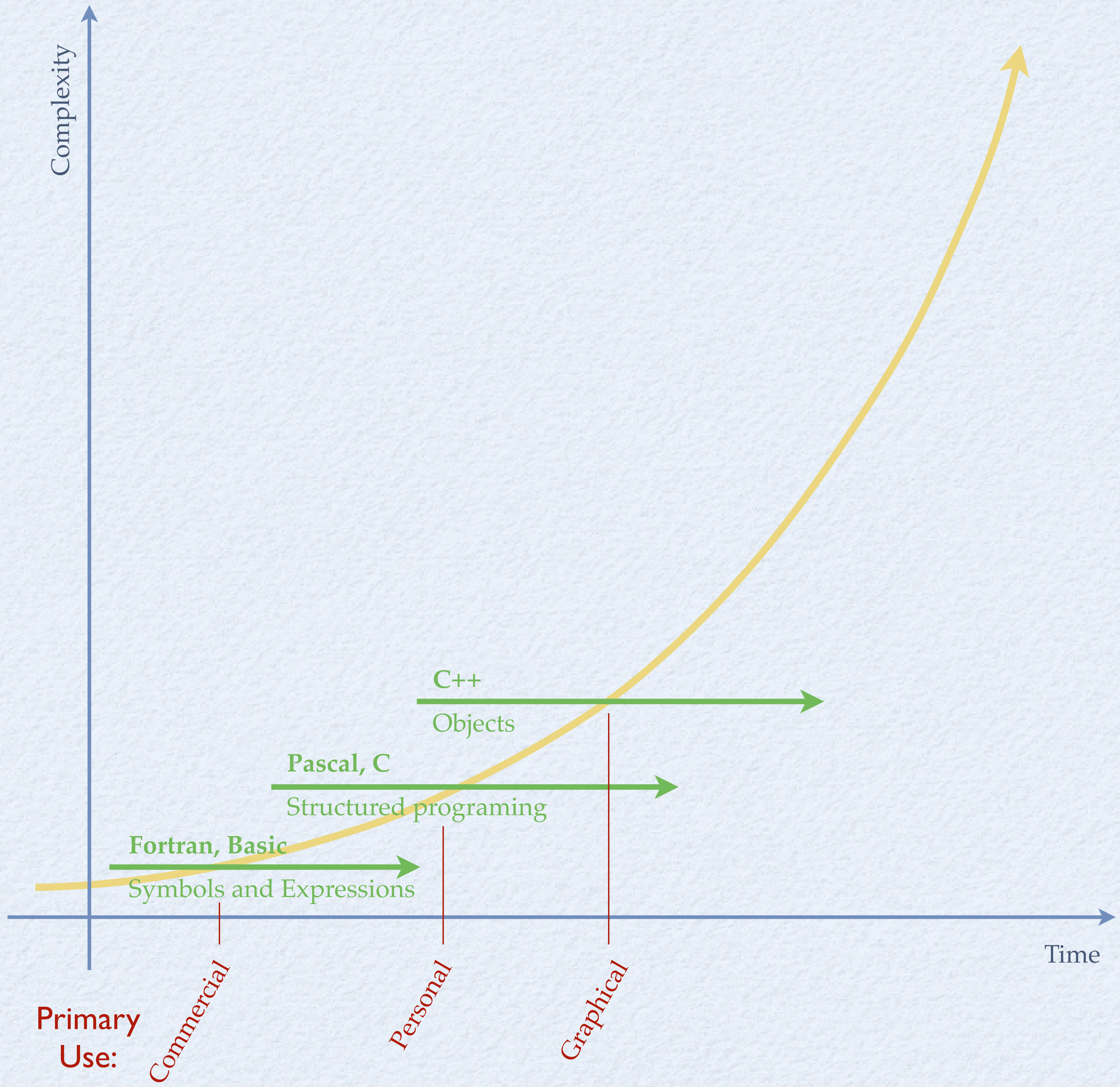

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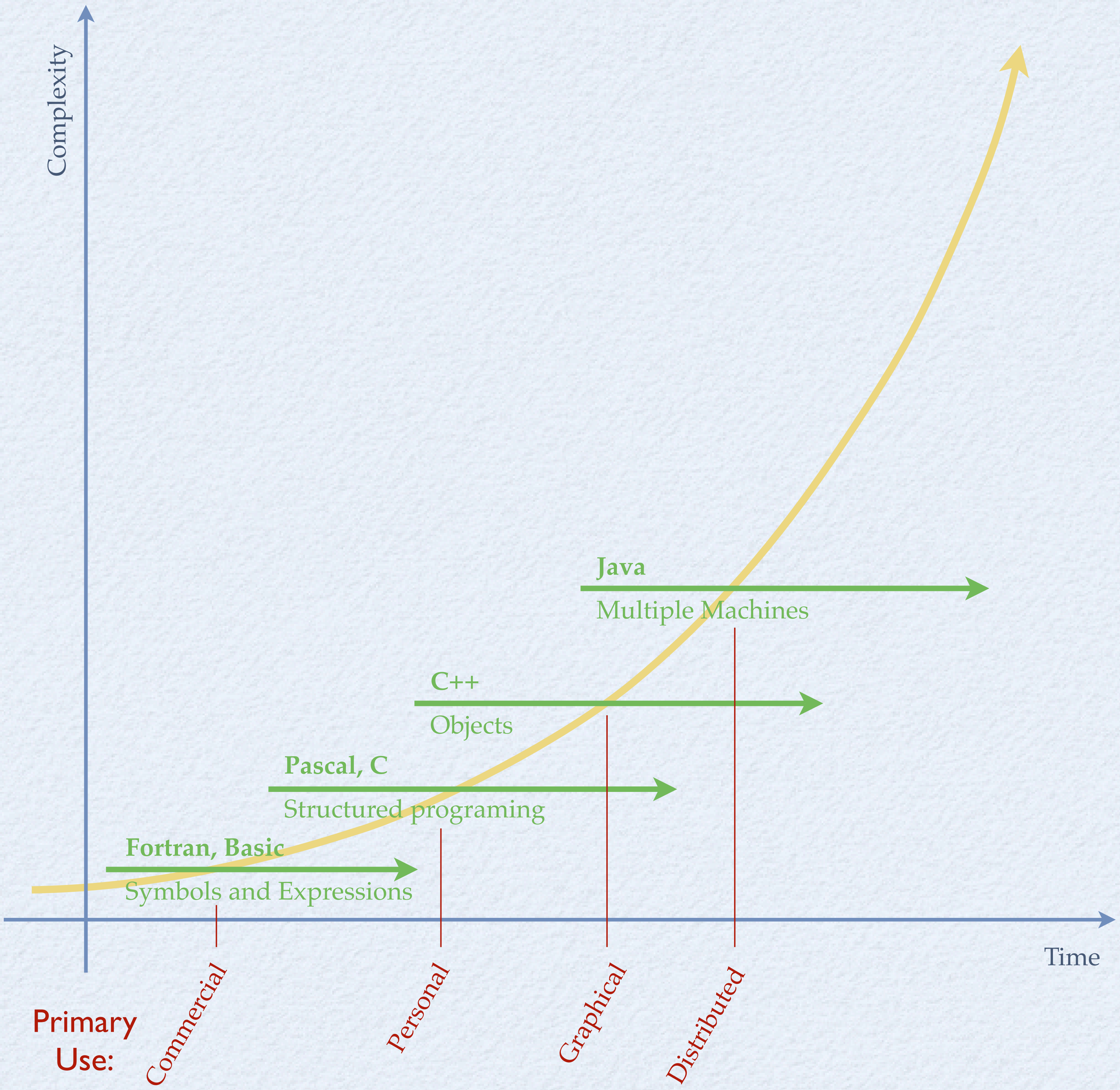

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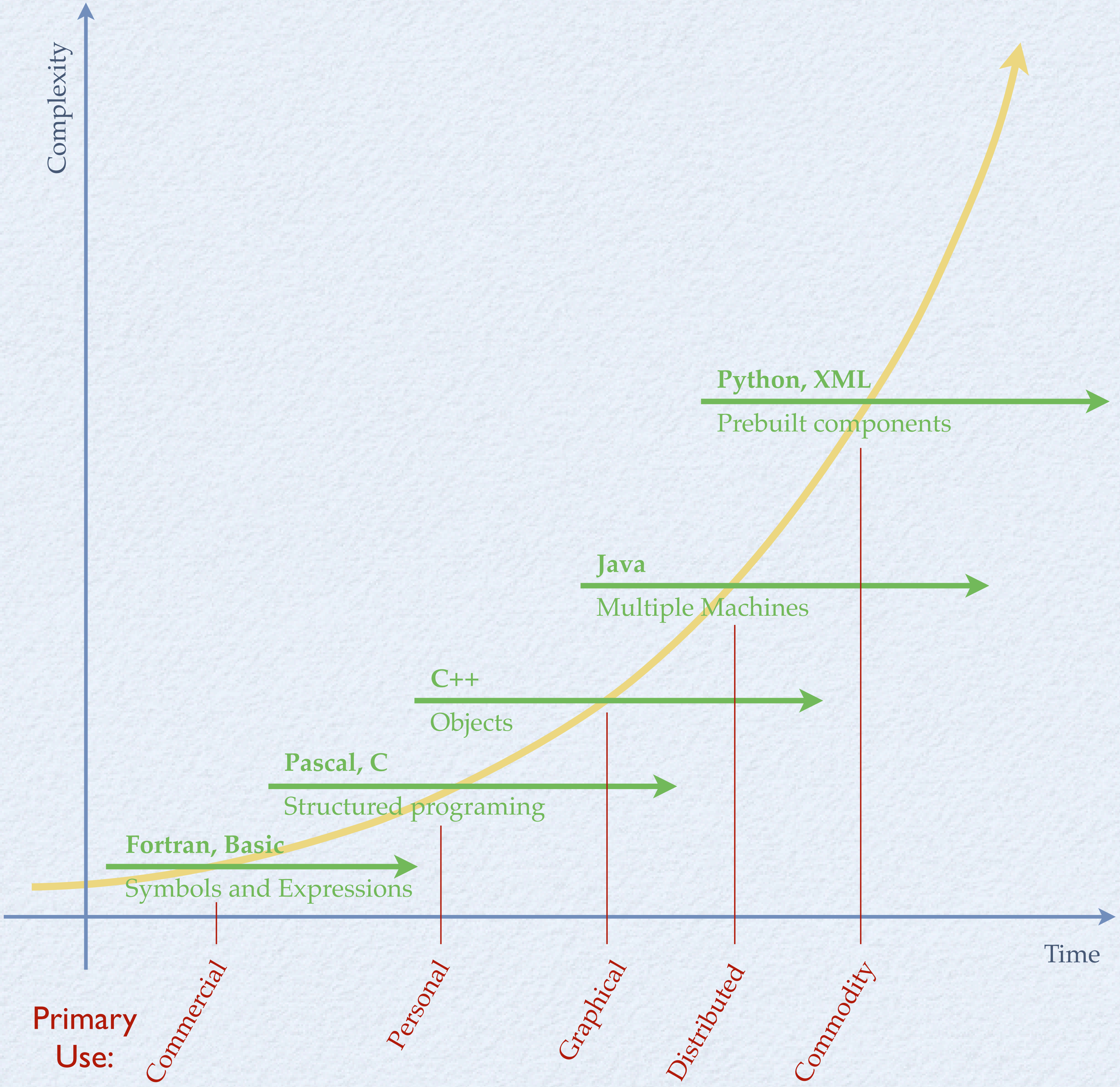

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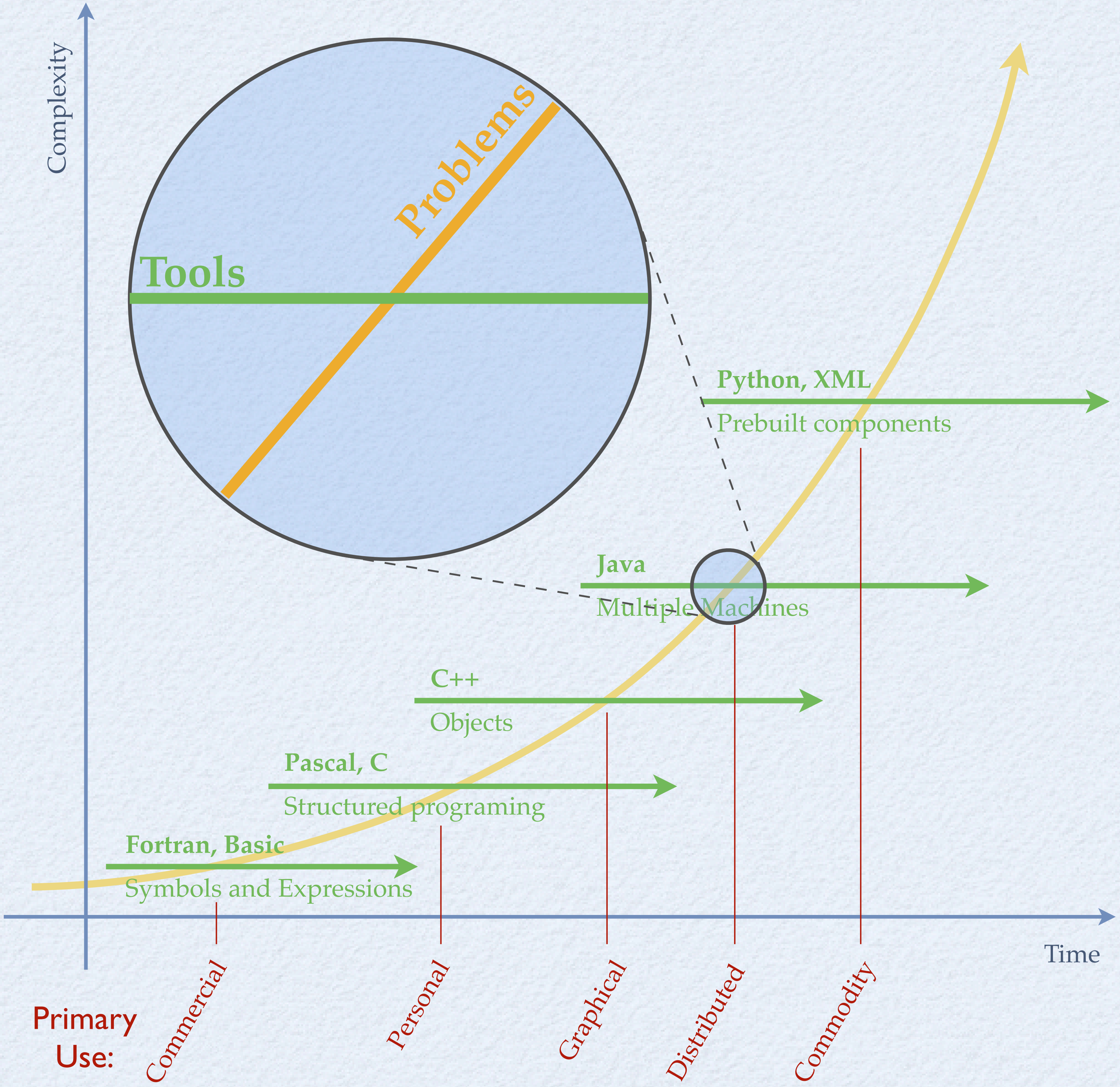

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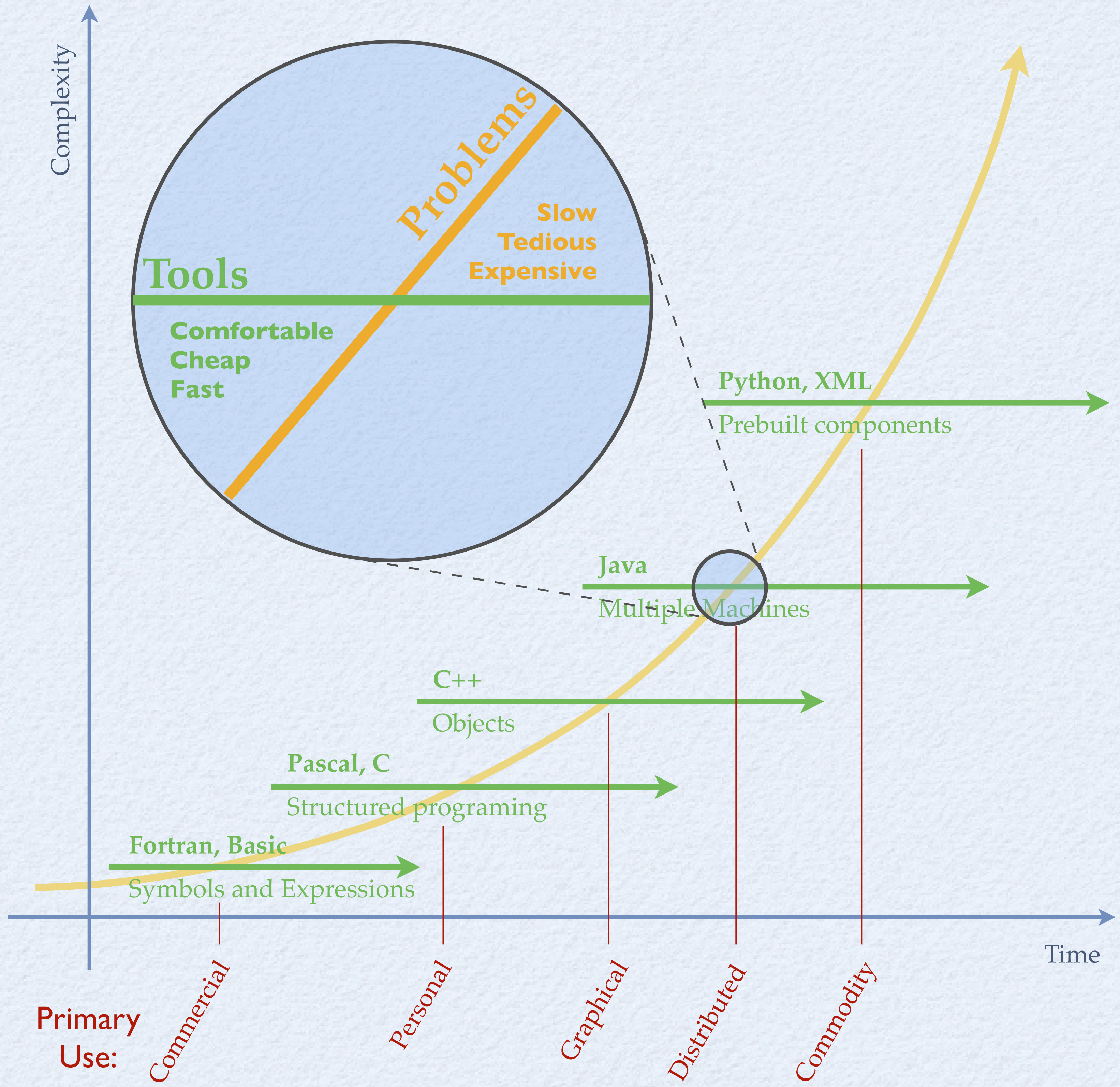

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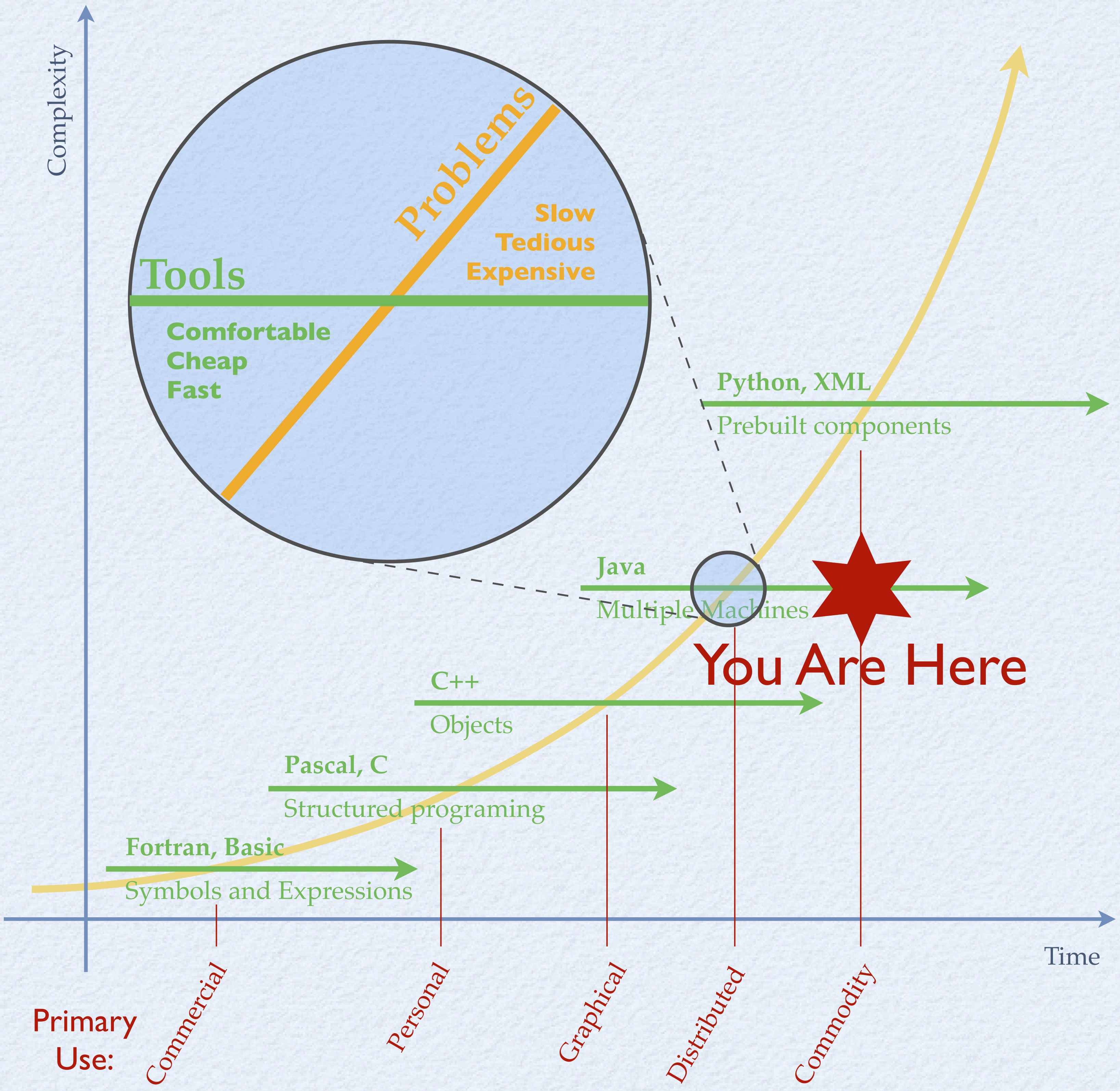

Complexity

Tools

Problems

Slow
Tedious
Expensive

Comfortable
Cheap
Fast

Python, XML
Prebuilt components

Java
Multiple Machines

C++
Objects

Pascal, C
Structured programing

Fortran, Basic
Symbols and Expressions

You Are Here

Time

Primary Use:

Commercial

Personal

Graphical

Distributed

Commodity

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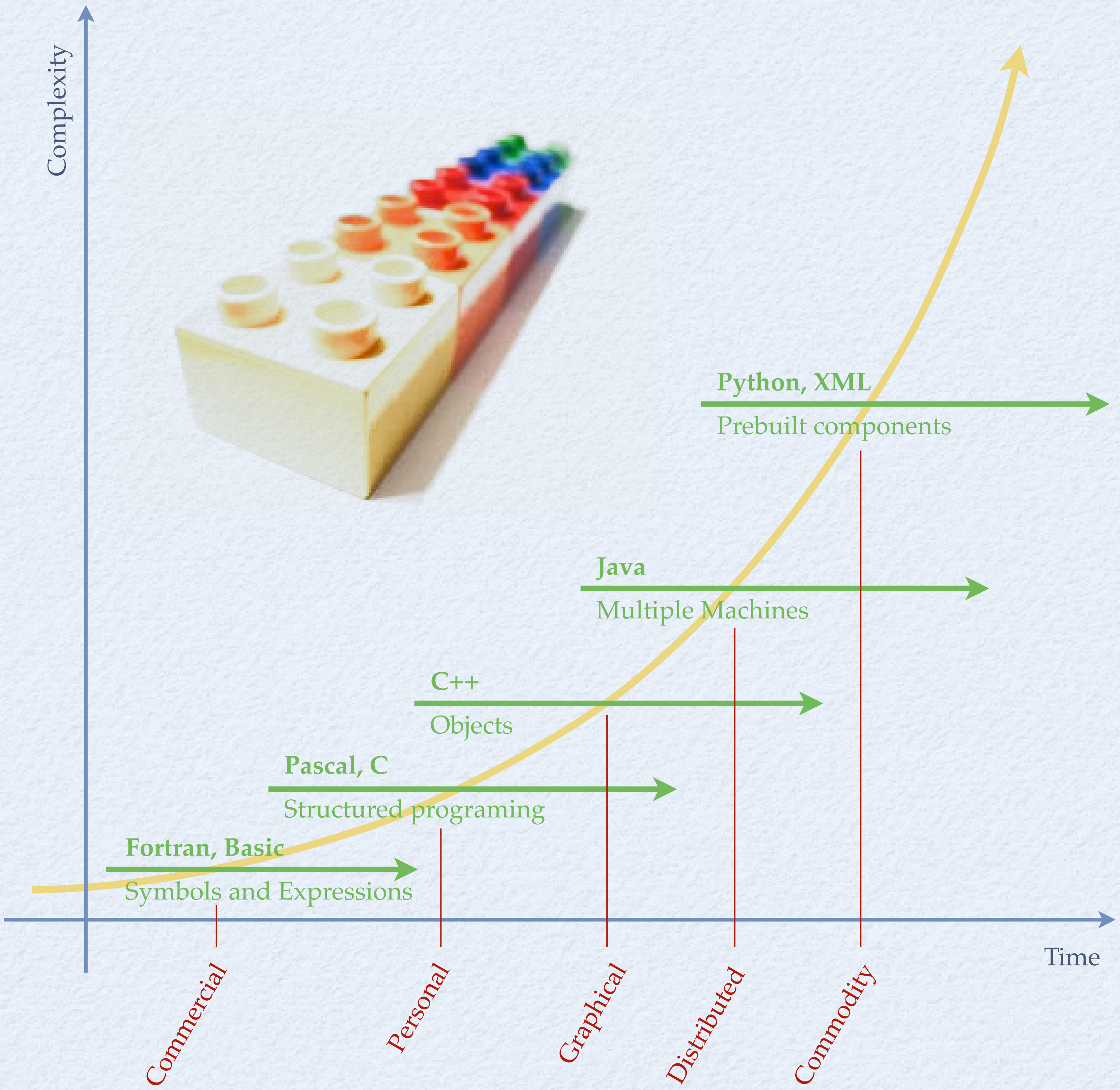
Staying Ahead of Moore's Law



- Can we integrate new paradigms incrementally?

  YES

- Can we select the best representation independently for any given concept?

  YES

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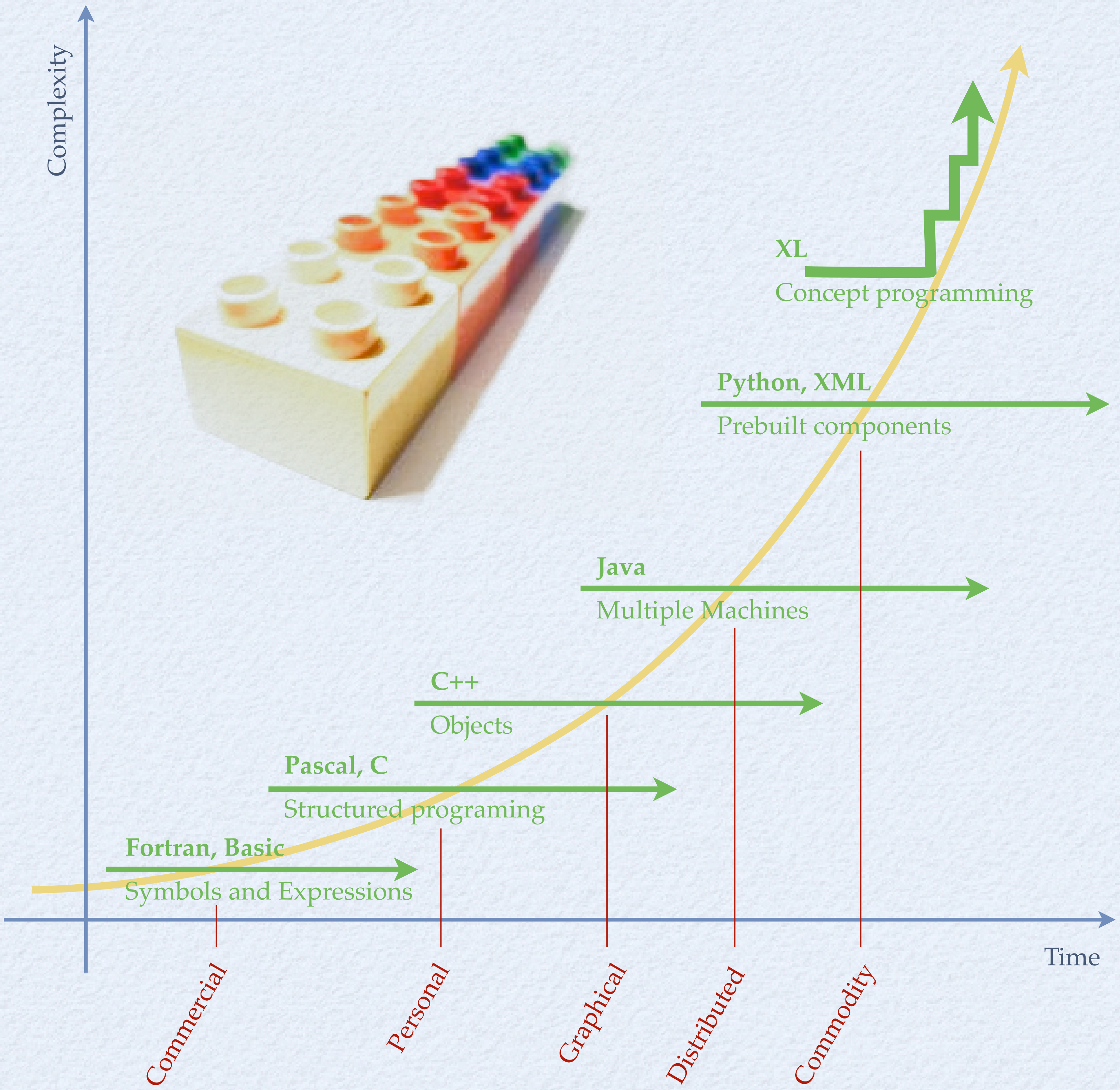

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Software Complexity

- Scale Complexity
  - Millions of Objects, Billions of Bits
- Domain Complexity
  - Ever Needed *"X-Ray Spectrography for Dummies?"*
- Artificial Complexity
  - C++ Standard: >700 pages, highly technical
- Business Complexity
  - Deliver this Yesterday, No Budget

The Belief in the Best Paradigm

- "Everything is an object"
  - In Smalltalk, `2+3*5=25`, not `17`
  - Object `2` gets message `+` with arg `3`
- "Everything is a function"
  - Functional languages: Lisp, OCaml
  - But the computer doesn't think that way
  - ... and neither do many of us

A Simple Example

How Can We Can Get Stuck so Easily?

Computing a Maximum

- Mathematical Definition is Well Known
  - Compares elements with an order relation
  - $Max(a_1, a_2, ..., a_n)$
- Not Exactly a New Problem in Computing
- That Ought to be Easy!

Maximum in C

- Generally Defined as a Macro
  - Something like: `#define max(x,y) ((x) < (y) ? (y) : (x))`
  - Or maybe: `#define max(x,y) ((x) >= (y) ? (x) : (y))`
- Some interesting questions
  - Why all the Parentheses?
  - What About Side Effects in `max(f(a++),c--)`?
  - What about `max(x,y,z,t)`?

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Failed!

Maximum in Java (using functions)

- Defined in `java.lang.Math` as overloaded functions
  - You get `max(int,int)`, `max(long, long)`, ...
- We got rid of side effects!
  - But what about `max(x,y,z,t)`?
  - What about `max("Hello", "World")`?
  - What about `max(1, 2.5)`?

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Maximum in Java (using Objects)

- Defined in `java.util.Collections` as generic function
  - When Java looks up to C++, you get:

```
public static <T extends Object & Comparable<? super T>>
T max(Collection<? extends T> coll)
```

- Hey, we can now compare more than 2 things!
  - But why can't we write `max(x,y,z,t)`?
  - Why should we create a collection to start with?
  - Why `e1.compareTo(e2)<0` and not `e1 < e2`?
  - Throws `ClassCastException` or `NoSuchElementException`

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Maximum in Lisp or Scheme

- Defined as variadic function
  - Scheme: `(define (max . a) (if (null? a) (error) (max-list a))`
- Much closer to an acceptable definition
  - Syntax is Natural for Lisp: `(max 1 2 3 5)`
  - Still fails at run-time in same cases as Java

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Failed!

Why Can't We Get It Right?

- That Ought to be Easy! But it's Hard
  - That simple problem is not solved after 30+ years
- There is a gap between:
  - Concepts, in your head
  - Representations of concepts, in the code
- Concept Programming is all about this gap

General Ideas

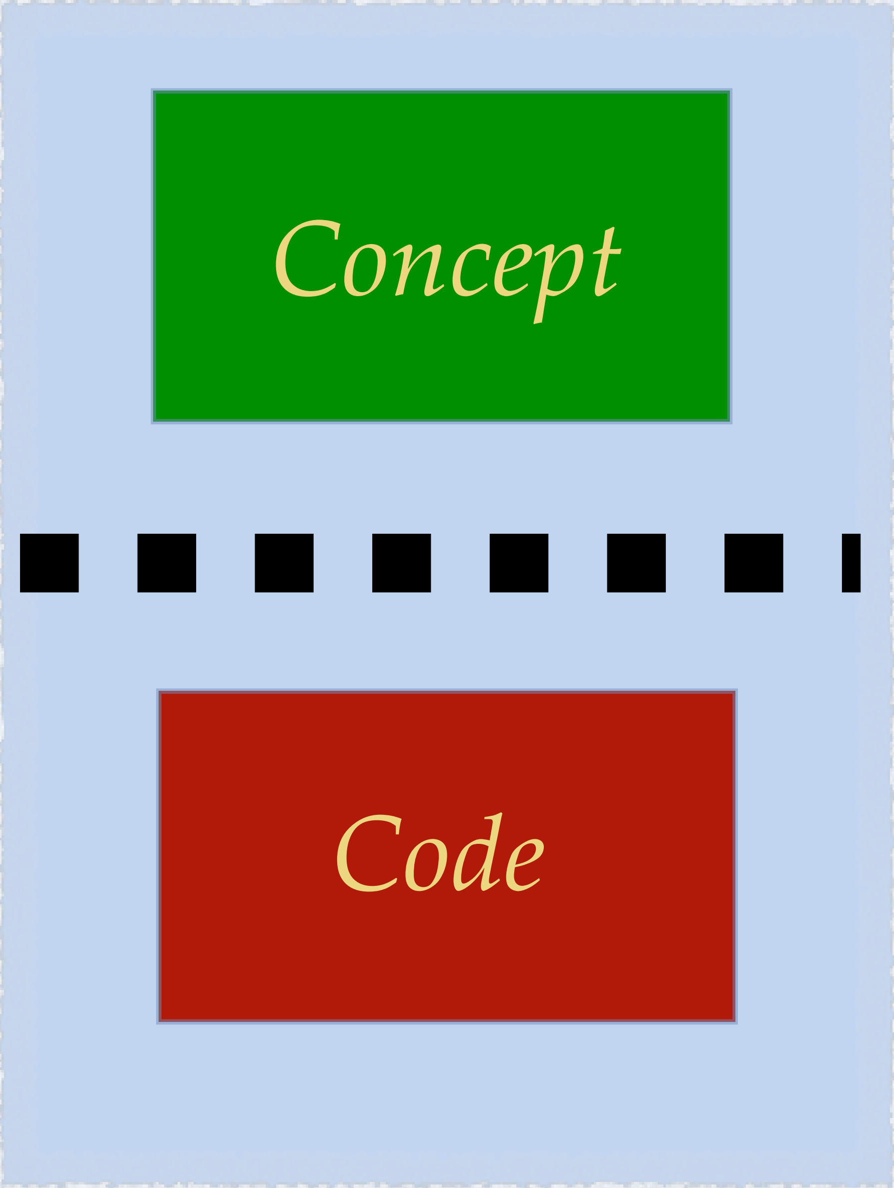
Applying Concept Programming

What is Concept Programming?

- Code represents concepts
  - Reality: Shape, File, Credit, Shotgun
  - Organization: Function, Visitor, Aspect
  - Focus on concepts relevant to the program
- Make the code “look like” the concept
  - Similarity in structure, behavior, locality
  - Principle of least surprise

Domains

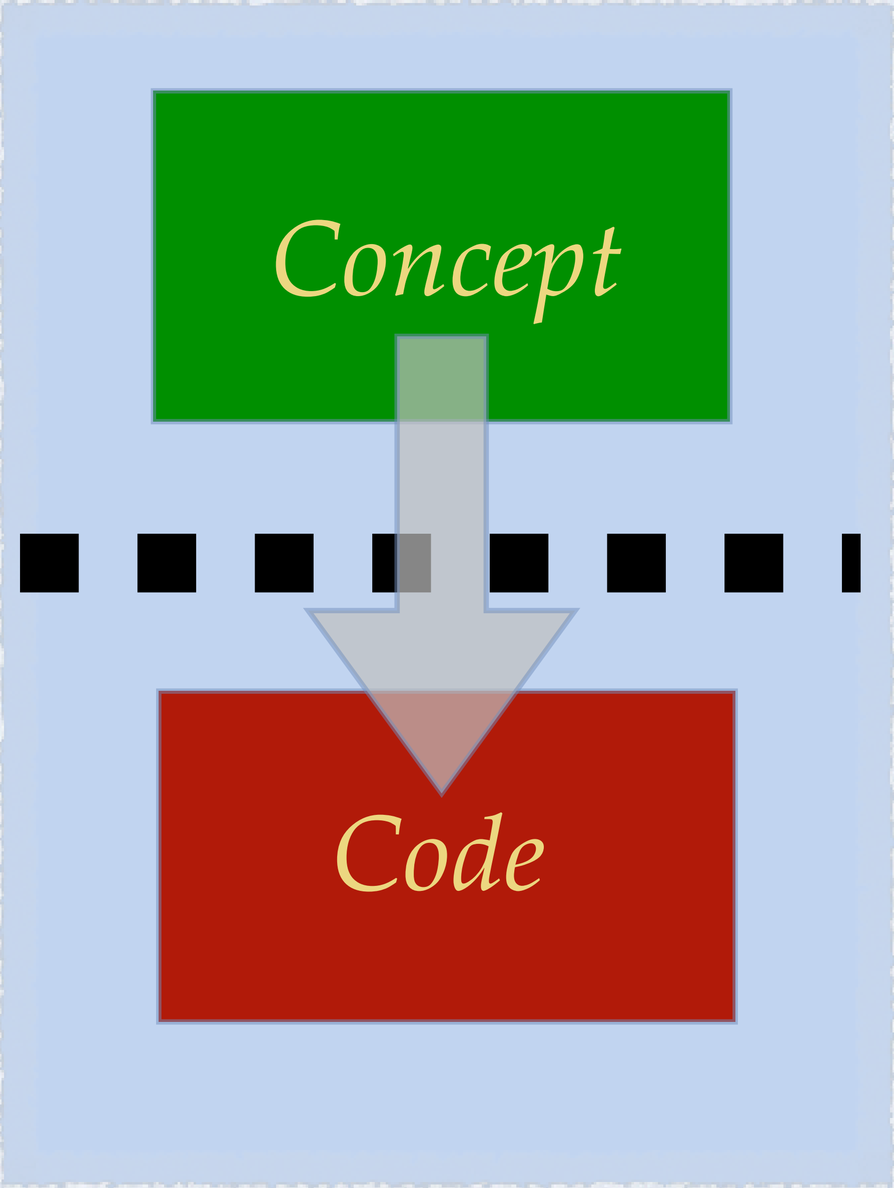
- Concept and Code live in separate domains
  - Concepts: Environment, Organization, Algorithms, Pictures
  - Code: Source, Object, Data, Instructions, Bitmaps
- Unlike objects or functions, you won't find "concepts" in the code, only concept representations



Bridging the Gap

- Turning Concepts into Code is a lossy conversion
  - This is true with any language, any paradigm
  - No two people have exactly the same concept in mind

- Minimizing the loss remains a worthy goal



What is a “Concept”?

- An entity in the problem space…
  - Cars, Error Messages, Connections
  - An object is only one possible representation
- … that is relevant to the code space
  - What will it be used for? How do we represent it?
  - Relevant here, irrelevant there
- The set of concepts is not constrained

Minority Paradigms

- The set of concepts is infinite...
  - Special concepts can make life easier
- Minority paradigms to fill the void
  - Logic programming, design by contract
- To each its (incompatible) language!
  - Prolog, Eiffel
- Not minor in usefulness
  - But the majority can't use them

Limitations of the Tools

- Many notations are difficult to add
  - Symbolic differentiation
  - GUI Elements
  - Debug-only code
- We Need a Concept Programming Language
  - But a lot can be done without

Pseudo Metrics

Identifying Non-Obvious Problems in the Code

Pseudo-metrics

- Syntactic Noise
  - Form that doesn’t map to the problem space
- Semantic Noise
  - Meaning that doesn’t map to the problem space
- Bandwidth
  - How much of the problem space is covered?
- Signal/Noise Ratio
  - How much code actually deals with real problems?

Pseudo-metrics

- Syntactic Noise
  - Form that doesn’t map to the problem space
  - Useless and potentially distracting visual clutter

  - C: `if (a == 3) { printf("Hello\n"); }`
  - C++: `list<list<int> > l; // Watch that space!`
  - HTML: `When N &lt; 0, N is said to be negative`

Pseudo-metrics

- Semantic Noise
  - Meaning that doesn't map to the problem space
  - Unexpected behavior compared to "native" concept

C: `if (x = 0) y = max(f(), x);`	Zeroes x, calls f twice
C++: `object.GetBounds(&rect);`	Exposes two addresses
Smalltalk: `2+3*5`	25 instead of 17

Pseudo-metrics

- Bandwidth
  - How much of the problem space is covered?
  - Conditions reuse in different cases

  - C: `int max(int x, int y);` vs. macro
  - C++: `cout << complex(2.3, 5.2);` vs. printf
  - Ada: `accept Help (X : item) do...` vs. pthreads

Pseudo-metrics

- Signal/Noise Ratio
  - How much code actually deals with real problems?
  - The rest is mostly useless fluff...
  - Java:

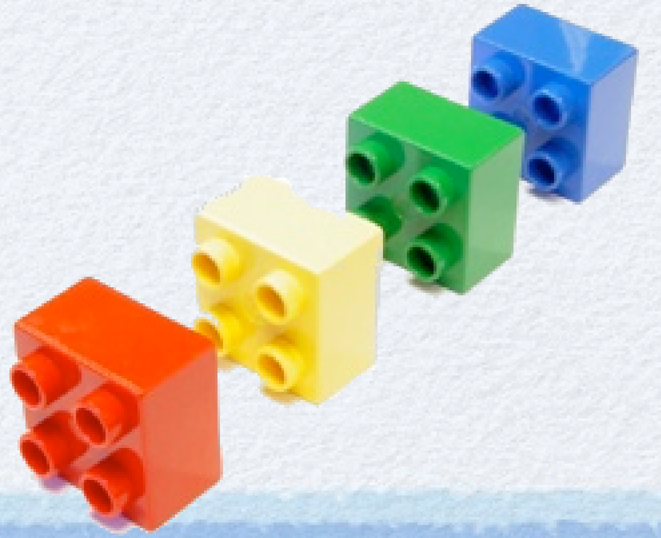
```
class HelloWorldApp {
    public static void main(String[] args) {
        System.out.println("Hello World!");
    }
}
```

Metrics: Keep in Mind

- These are pseudo metrics
  - You can’t measure things in the problem space
  - Highly subjective metrics
  - You can’t write a tool to measure them
- Analogy to Music
  - Reducing noise is a worthy goal...
  - But you cannot completely eliminate it
  - Noise to one, music to the other

Abstraction

Fighting Complexity by Reducing it to Tiny Bits



Abstractions

- Code is a particular concept abstraction
- This abstraction is necessary
  - You can’t run ideas in a computer
- But: Abstractions introduce distortions
  - What you think is not what you get
  - Abstraction penalty, inefficiency in generated code

Abstraction Loss: Concept Cast

- Replacing a concept with a related one
  - Often to workaround limits of the tools
  - Example: replace f(x,y,z,...) with f(list)
- Too often an unconscious decision
  - It works!
- Maybe the most frequent abstraction loss
  - You lose some semantic signal...
  - ... while introducing a lot of noise

Abstractions vs. Complexity

- *Domain*: Equivalence, aka least surprise
  - Programmers read `FILE` and think “file”
- *Scale*: Layering and reuse
  - `FILE` can be reused, e.g. to build `DATABASE`
- *Artificial*: Hide irrelevant details
  - You can safely ignore all the OS magic behind `FILE`
- *Business*: Manageability, predictability
  - `FILE` behavior is reliable, portable, documented

Step by Step

- Define the problem space
- Identify individual concepts
- Document concept behaviors & relations
- Choose notation for each concept
- Select or invent representation

XL: An Extensible Language

Applying Concept Programming to Language Design

Considering Metrics

- Syntactic Noise

```
if A < 3 then IO.WriteLn "A=", A
```

- Semantic Noise

```
to GetBounds(O : object; out R : rectangle)
```

- Bandwidth

```
function Max(x: ordered; ...) return ordered
X : integer := Max(1, 3, 7, 2, 4)
```

- Signal/Noise Ratio

```
type complex with
    Re, Im : real
```

Extensibility

- Symbolic differentiation
  - Standard notation: $\frac{\mathrm{d}}{\mathrm{d}x}\sin(x+\frac{1}{x})$
  - XL notation: `{differentiation} d/dx(sin(x+1/x))`
- Compiler plug-ins implement extensions
  - Plug-in code uses specific extensions:

```
translation differentiation
    when (d/'dvar'('expr')) where BeginsWithD(dvar) then ...
```

Extensibility benefits

- Represent arbitrary concepts
- Favors “natural” notations in the code
- Unifies “user” and “built-in” entities
- Leaves the computer to do the grunt work

XL Concept-inspired Features

- Expression reduction
- True and validated generic types
- Type-safe variable argument lists
- Iterators and generators

- All used to build “standard” elements

XL Concept-inspired Features

- Expression reduction
  - Generalizes operator overloading
  - Efficient matrix linear algebra

```
function MultiplyAdd(A, B, C : matrix) return matrix
    written A*B+C
```

  - Easy special cases

```
function IsIdentity(M : matrix) return boolean
    written M = 1
```

XL Concept-inspired Features

- True generic types
  - Make functions implicitly generic
  - Array operations

    ```
    function Add (A, B : array) return array written A+B
    ```

  - Pointer operations

    ```
    function Peek(P : ptr) return ptr.item written *P
    to Poke(P : ptr; V : ptr.item) written *P := V
    ```

XL Concept-inspired Features

- Validated generic types
  - Specify interface of a generic type
  - Type with an order operation

```
generic type ordered where
     A, B : ordered                  // Code testing the
     Test : boolean := A < B         // candidate types
```

  - Makes generic code more robust

```
function Min (X : ordered) return ordered
Z : complex := Min(Z)                // Error (unlike C++)
```

XL Concept-inspired Features

- Type-safe variable argument lists
  - A user-defined Pascal-style WriteLn:

```
to WriteLn(...) is          // ... stand for rest of args
     Write ...              // Pass rest of args
     Write new_line
```

  - Min and max functions that work:

```
function Min(X : ordered; ...) return ordered is
     result := Min(...)
     if X < result then
        result := X
```

XL Concept-inspired Features

- Iterators and generators
  - Define iterator over a range of integers

```
iterator It(var out C : T; L,H: T)  written C in L..H is
    C := L
    while C <= H loop
        yield
        C += 1
```

  - Used *in for loops (and implements for loops)*

```
for K in 3..5 loop
    WriteLn "K=", K
```

Maximum in XL

```
generic type ordered where
    A, B : ordered
    Test : boolean := A < B

function Max (X : ordered) return ordered is
    return X

function Max (X : ordered; ...) return ordered is
    result := Max(...)
    if result < X then
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Pass

Bridging the Gap: Done?

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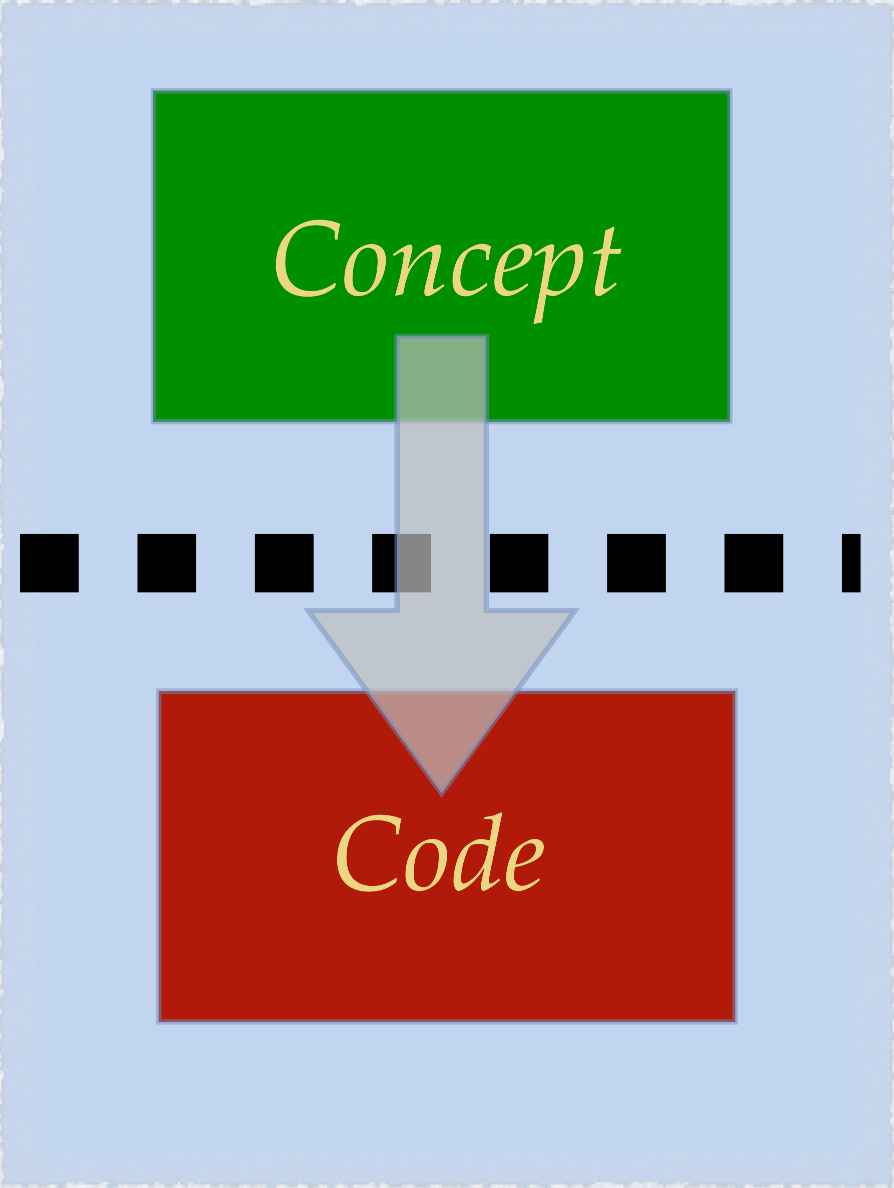
- XL does this better



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