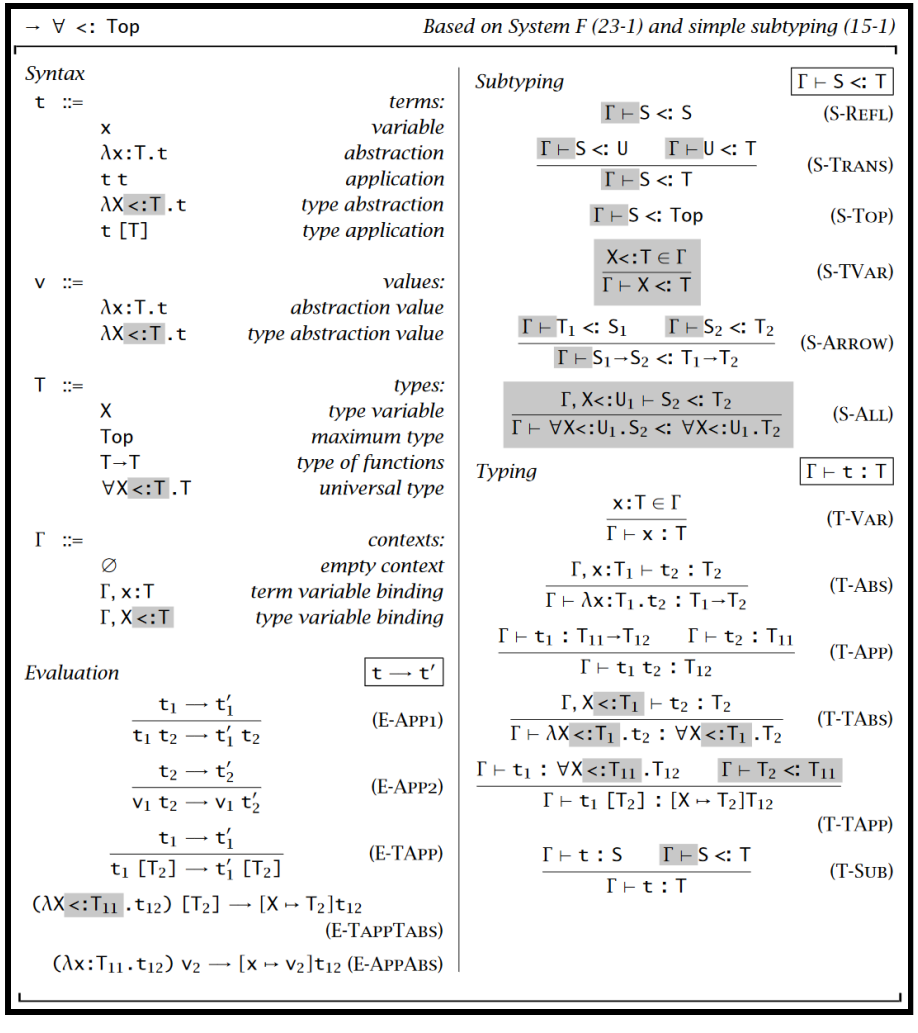
Write your own tiny programming system(s)

Programming languages and systems

Tomas Petricek, Charles University

tomas@tomasp.net
@tomasp.net
https://tomasp.net
https://d3s.mff.cuni.cz/teaching/nprg077



→ ∀ <: Top — *Based on System F (23-1) and simple subtyping (15-1)*

Syntax

t ::=		*terms:*
	x	*variable*
	λx:T.t	*abstraction*
	t t	*application*
	λX<:T.t	*type abstraction*
	t [T]	*type application*
v ::=		*values:*
	λx:T.t	*abstraction value*
	λX<:T.t	*type abstraction value*
T ::=		*types:*
	X	*type variable*
	Top	*maximum type*
	T→T	*type of functions*
	∀X<:T.T	*universal type*
Γ ::=		*contexts:*
	∅	*empty context*
	Γ, x:T	*term variable binding*
	Γ, X<:T	*type variable binding*

Evaluation — $t \longrightarrow t'$

$$\frac{t_1 \longrightarrow t_1'}{t_1\ t_2 \longrightarrow t_1'\ t_2}\ \text{(E-App1)} \qquad \frac{t_2 \longrightarrow t_2'}{v_1\ t_2 \longrightarrow v_1\ t_2'}\ \text{(E-App2)} \qquad \frac{t_1 \longrightarrow t_1'}{t_1\ [T_2] \longrightarrow t_1'\ [T_2]}\ \text{(E-TApp)}$$

$$(\lambda X{<:}T_{11}.t_{12})\ [T_2] \longrightarrow [X \mapsto T_2]t_{12}\ \text{(E-TappTabs)}$$

$$(\lambda x{:}T_{11}.t_{12})\ v_2 \longrightarrow [x \mapsto v_2]t_{12}\ \text{(E-AppAbs)}$$

Subtyping — $\Gamma \vdash S <: T$

$$\Gamma \vdash S <: S\ \text{(S-Refl)} \qquad \frac{\Gamma \vdash S <: U \quad \Gamma \vdash U <: T}{\Gamma \vdash S <: T}\ \text{(S-Trans)} \qquad \Gamma \vdash S <: \text{Top}\ \text{(S-Top)}$$

$$\frac{X{<:}T \in \Gamma}{\Gamma \vdash X <: T}\ \text{(S-TVar)} \qquad \frac{\Gamma \vdash T_1 <: S_1 \quad \Gamma \vdash S_2 <: T_2}{\Gamma \vdash S_1 \to S_2 <: T_1 \to T_2}\ \text{(S-Arrow)}$$

$$\frac{\Gamma, X{<:}U_1 \vdash S_2 <: T_2}{\Gamma \vdash \forall X{<:}U_1.S_2 <: \forall X{<:}U_1.T_2}\ \text{(S-All)}$$

Typing — $\Gamma \vdash t : T$

$$\frac{x{:}T \in \Gamma}{\Gamma \vdash x : T}\ \text{(T-Var)} \qquad \frac{\Gamma, x{:}T_1 \vdash t_2 : T_2}{\Gamma \vdash \lambda x{:}T_1.t_2 : T_1 \to T_2}\ \text{(T-Abs)}$$

$$\frac{\Gamma \vdash t_1 : T_{11} \to T_{12} \quad \Gamma \vdash t_2 : T_{11}}{\Gamma \vdash t_1\ t_2 : T_{12}}\ \text{(T-App)} \qquad \frac{\Gamma, X{<:}T_1 \vdash t_2 : T_2}{\Gamma \vdash \lambda X{<:}T_1.t_2 : \forall X{<:}T_1.T_2}\ \text{(T-TAbs)}$$

$$\frac{\Gamma \vdash t_1 : \forall X{<:}T_{11}.T_{12} \quad \Gamma \vdash T_2 <: T_{11}}{\Gamma \vdash t_1\ [T_2] : [X \mapsto T_2]T_{12}}\ \text{(T-TApp)} \qquad \frac{\Gamma \vdash t : S \quad \Gamma \vdash S <: T}{\Gamma \vdash t : T}\ \text{(T-Sub)}$$

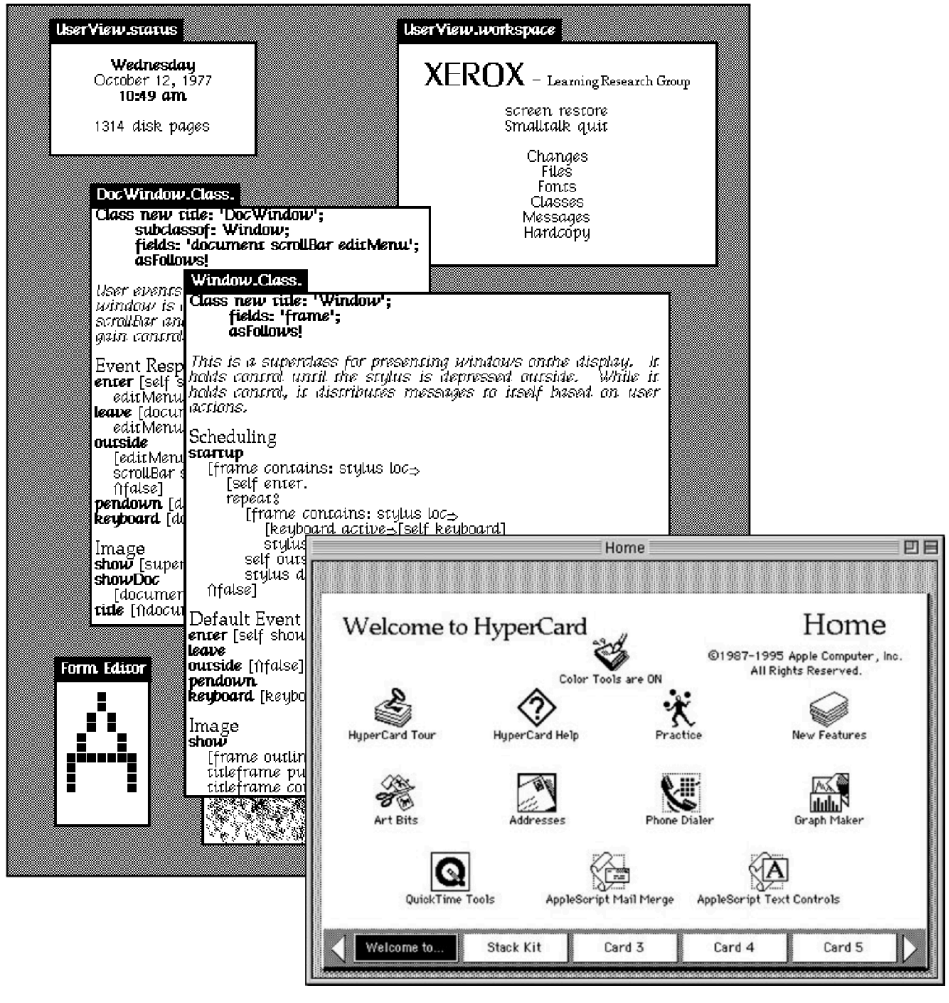
Programming Languages

Programming is writing code

Formal semantics, implementation, paradigms, types

We know how to study this!

Charles University



Programming Systems

Interacting with a stateful system

Feedback, liveness, interactive user interfaces

But how do we study this?

Charles University

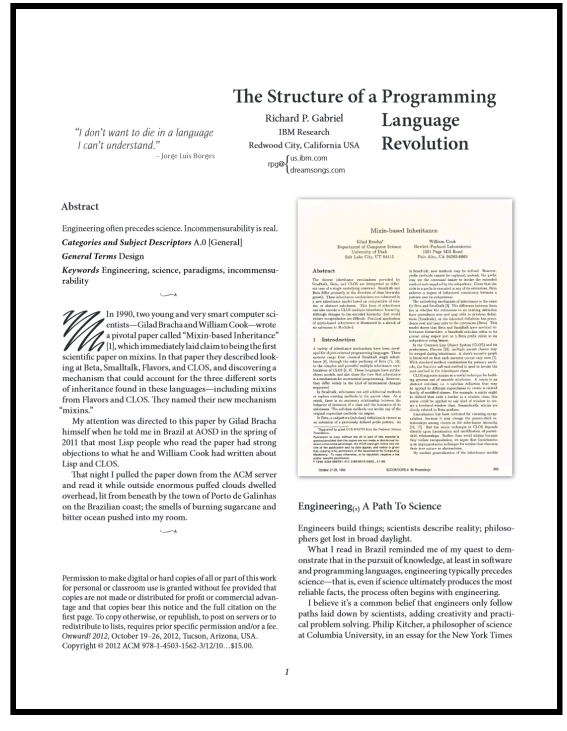
Paradigm shift in 1990s

From systems to languages

- From running system to code
- From state & interaction to semantics
- Incommensurable ways of thinking!

History of science matters!

- How did we get where we are?
- What ideas got lost along the way?
- How to recover them?



The Structure of a Programming Language Revolution

Richard P. Gabriel
IBM Research
Redwood City, California USA
rpg@{us.ibm.com, dreamsongs.com}

"I don't want to die in a language I can't understand."
– Jorge Luis Borges

Abstract

Engineering often precedes science. Incommensurability is real.

Categories and Subject Descriptors A.0 [General]

General Terms Design

Keywords Engineering, science, paradigms, incommensurability

In 1990, two young and very smart computer scientists—Gilad Bracha and William Cook—wrote a pivotal paper called "Mixin-based Inheritance" [1], which immediately laid claim to being the first scientific paper on mixins. In that paper they described looking at Beta, Smalltalk, Flavors, and CLOS, and discovering a mechanism that could account for the three different sorts of inheritance found in these languages—including mixins from Flavors and CLOS. They named their new mechanism "mixins."

My attention was directed to this paper by Gilad Bracha himself when he told me in Brazil at AOSD in the spring of 2011 that most Lisp people who read the paper had strong objections to what he and William Cook had written about Lisp and CLOS.

That night I pulled the paper down from the ACM server and read it while outside enormous puffed clouds dwelled overhead, lit from beneath by the town of Porto de Galinhas on the Brazilian coast; the smells of burning sugarcane and bitter ocean pushed into my room.

Onward! 2012, October 19–26, 2012, Tucson, Arizona, USA.

Mixin-based Inheritance

Gilad Bracha
Department of Computer Science
University of Utah
Salt Lake City, UT 84112

William Cook
Hewlett-Packard Laboratories
1501 Page Mill Road
Palo Alto, CA 94304-0969

Abstract

1 Introduction

Engineering$_{(0)}$ A Path To Science

Engineers build things; scientists describe reality; philosophers get lost in broad daylight.

What I read in Brazil reminded me of my quest to demonstrate that in the pursuit of knowledge, at least in software and programming languages, engineering typically precedes science—that is, even if science ultimately produces the most reliable facts, the process often begins with engineering.

I believe it's a common belief that engineers only follow paths laid down by scientists, adding creativity and practical problem solving. Philip Kitcher, a philosopher of science at Columbia University, in an essay for the New York Times

1

Charles University

Language paradigms

Functional programming

No mutable state, everything a function

Imperative programming

Mutable memory with pointers

Object-oriented programming

Everything an object, hides its own logic

Logic programming

Declare facts and use inference

Charles University

Demo

Logic programming in Prolog

System interaction

- Command line programming systems
  Code editor, compiler, build tools, etc.
- Image-based programming model
  Programming system is always running
- Interactive and live programming
  System provides continuous feedback
- Incremental or reactive evaluation
  Recompute on edit or when new data come

Charles University

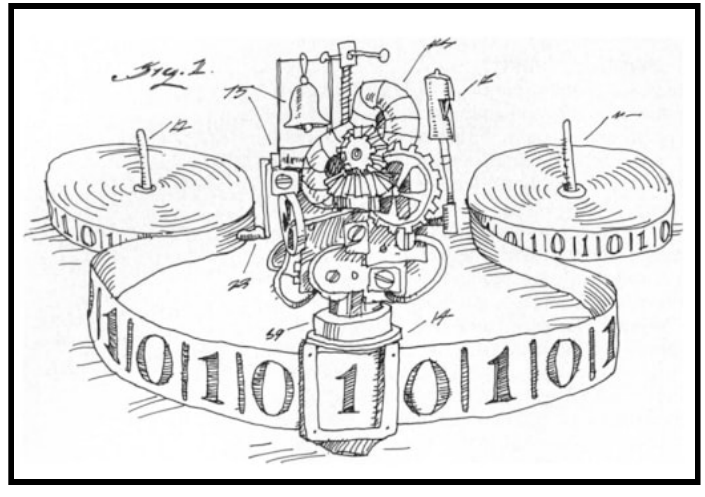
Demo

Object-orientation in Smalltalk

What really matters?

Static structure (program)

- Source code of the program
- What you have at the start



Dynamic structure (process)

- Runtime data structures
- What else do you need to run

Logic of evaluation (execution)

- How the dynamic state evolves?

Charles University

$$\text{(deref)} \quad \langle !\ell, s\rangle \longrightarrow \langle n, s\rangle \quad \text{if } \ell \in \mathrm{dom}(s) \text{ and } s(\ell) = n$$

$$\text{(assign1)} \quad \langle \ell := n, s\rangle \longrightarrow \langle \textbf{skip}, s + \{\ell \mapsto n\}\rangle \quad \text{if } \ell \in \mathrm{dom}(s)$$

$$\text{(assign2)} \quad \frac{\langle e, s\rangle \longrightarrow \langle e', s'\rangle}{\langle \ell := e, s\rangle \longrightarrow \langle \ell := e', s'\rangle}$$

$$\text{(seq1)} \quad \langle \textbf{skip}; e_2, s\rangle \longrightarrow \langle e_2, s\rangle$$

$$\text{(seq2)} \quad \frac{\langle e_1, s\rangle \longrightarrow \langle e_1', s'\rangle}{\langle e_1; e_2, s\rangle \longrightarrow \langle e_1'; e_2, s'\rangle}$$

$$\text{(if1)} \quad \langle \textbf{if } \textbf{true } \textbf{then } e_2 \textbf{ else } e_3, s\rangle \longrightarrow \langle e_2, s\rangle$$

$$\text{(if2)} \quad \langle \textbf{if } \textbf{false } \textbf{then } e_2 \textbf{ else } e_3, s\rangle \longrightarrow \langle e_3, s\rangle$$

$$\text{(if3)} \quad \frac{\langle e_1, s\rangle \longrightarrow \langle e_1', s'\rangle}{\langle \textbf{if } e_1 \textbf{ then } e_2 \textbf{ else } e_3, s\rangle \longrightarrow \langle \textbf{if } e_1' \textbf{ then } e_2 \textbf{ else } e_3, s'\rangle}$$

Operational semantics

Standard approach to programming language theory

Why write small interpreters instead?

Charles University

```
(* A term like 'father(william, X)'
   consists of predicate 'father',
   atom 'william' and variable 'X' *)
type Term =
  | Atom of string
  | Variable of string
  | Predicate of string * Term list

(* A rule 'head(...) :- body.' *)
type Rule =
  { Head : Term
    Body : Term list }

(* A program is a list of rules *)
type Program = Rule list
```

Code can run!

A good way to explain the structures!

1) Functional data types for the static and dynamic structure

2) A function to model the evaluation logic

Charles University