NPRG077

TinyProlog: Tiny declarative logic programming language

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Logic programming

- **Declarative style** - specify what, but not how
- Programs consists of **facts and rules**
- Evaluation by clever **inference engine**
- **Prolog, Datalog** and basis of other systems
- Origins in AI and **natural language**

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From inference to programming

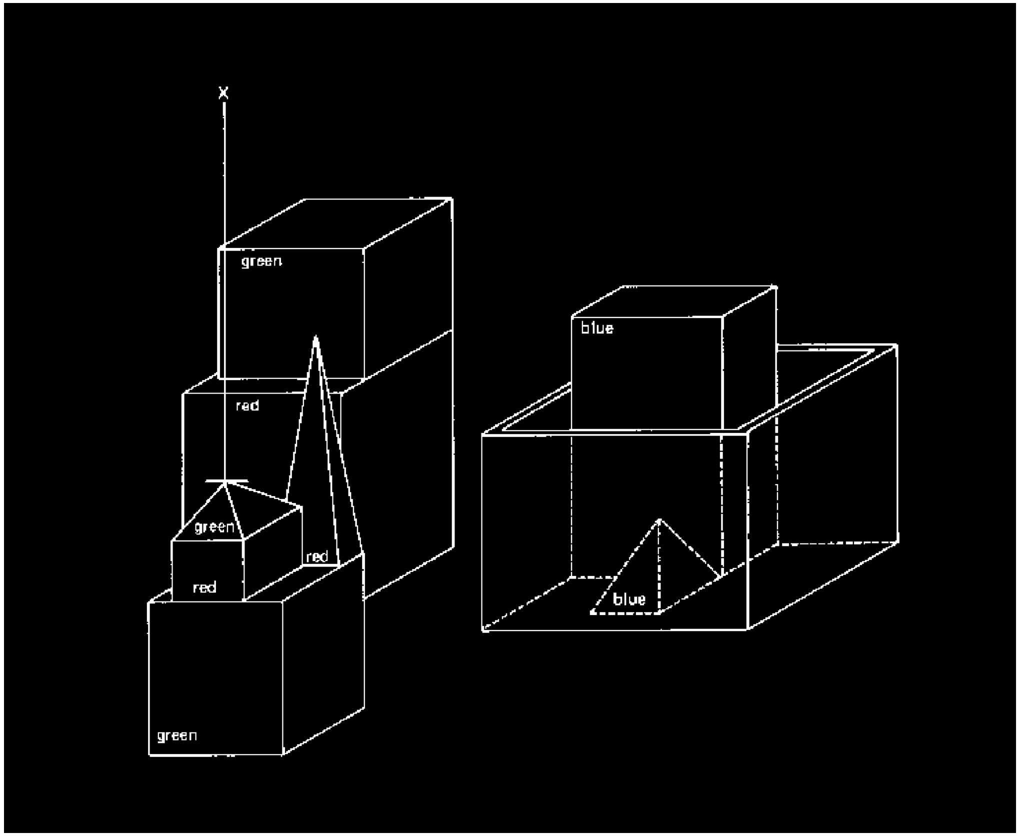
Type inference

- Program analysis
- Generated constraints
- Unification of types
- Infer type assignment
- Unification + substitution

Logic programming

- Program evaluation
- Handwritten programs
- Unification of terms
- Infer variable assignment
- Unification + substitution

A bit of history



Natural language processing in the late 1960s & early 1970s

SHRDLU, PLANNER

"Find a block which is taller than the one you are holding and put it into the box."

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Prolog then and now

Alain Colmerauer, Marseilles (1972)

- Natural language processing
- Automatic theorem proving

Fifth generation systems (1980s)

- 10 year initiative in Japan
- Epoch-making knowledge processing

Prolog (and Datalog) today

- Used in real-world in specialized domains
- Basic of many reasoning & solving systems

TinyProlog

Logic programming by example

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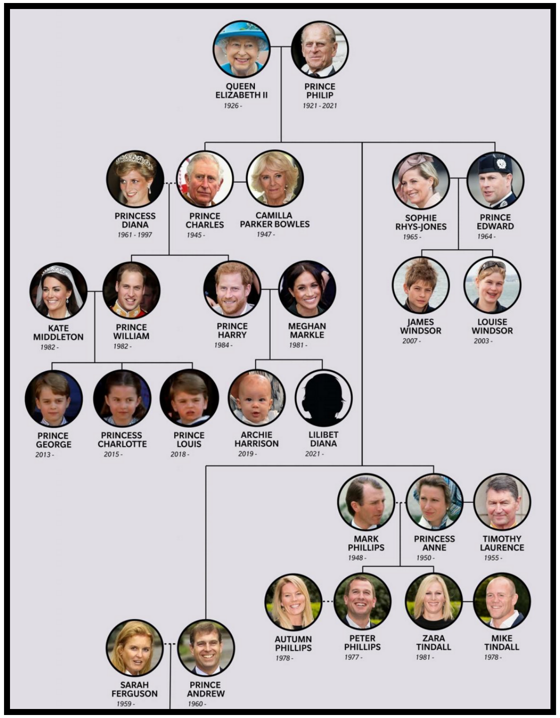
Prolog "Hello world"

Family tree querying

- Simple database querying
- Search for data patterns
- Grandparent (parent of a parent)
  Father (parent who is male)



List processing

- Linked lists with "cons" and "nil"
- Matching lists with patterns
- Many functions become multi-purpose

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Demo

Family tree and lists

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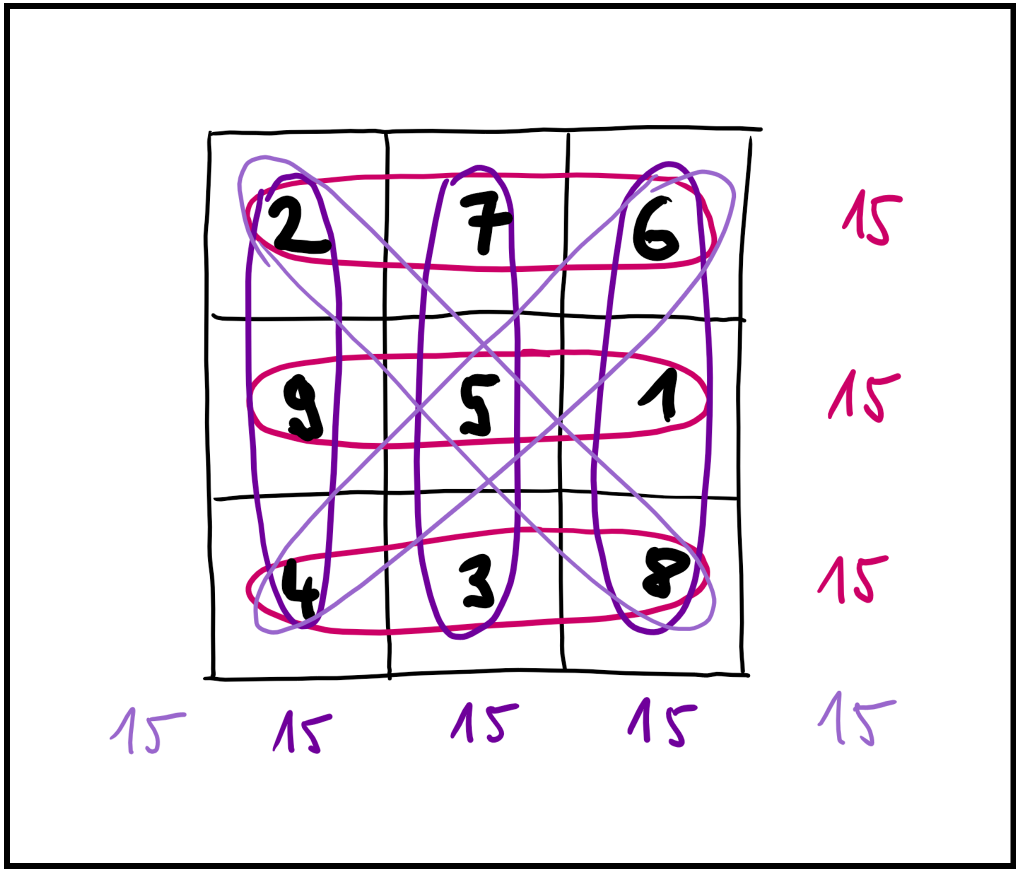

Magic squares

Naive method

Generate & test
all permutations

Better approaches

Try adding only
reasonable options

Naive is fine for us!

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Demo

Generating magic squares

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TinyProlog

A bit of theory

Model of knowledge

Closed world assumption

- Only declared facts are true
- No unknown children exist!
- Shapes the semantics of Prolog

Negation in Prolog

- Yes means provably true
- No means not provably true
- False only in a closed world

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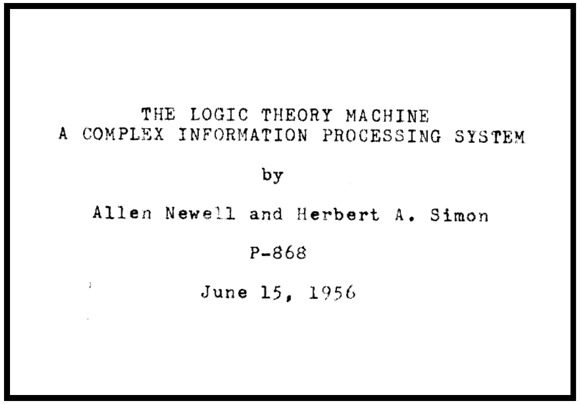
Theory behind resolution

Prolog programs as logic clauses

- Horn clause: $A \leftarrow B_1 \wedge B_2 \wedge \ldots \wedge B_n$
- Equivalent: $A \vee \neg B_1 \vee \neg B_2 \vee \ldots \vee \neg B_n$



THE LOGIC THEORY MACHINE
A COMPLEX INFORMATION PROCESSING SYSTEM

by

Allen Newell and Herbert A. Simon

P-868

June 15, 1956

SLD resolution in Prolog

- Sound and refutation-complete resolution for Horn clauses
- Will prove 'false' if possible

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Variables in Prolog clauses

Universally quantified over formula, existentially over body

$$\forall x \forall y (grandparent(x, y) \leftarrow \exists z (parent(x, z) \wedge parent(z, y)))$$

Transformed using standard logical operations

$$\forall x \forall y (grandparent(x, y) \vee \neg \exists z (parent(x, z) \wedge parent(z, y)))$$
$$\forall x \forall y (grandparent(x, y) \vee \forall z \neg (parent(x, z) \wedge parent(z, y)))$$
$$\forall x \forall y \forall z (grandparent(x, y) \vee \neg parent(x, z) \vee \neg parent(z, y))$$

We need to use free variables when applying rule!

Numbers

Calculating inside Prolog

- Peano arithmetic encoded as zero & successor
- Constraint Logic Programming (CLP) extensions
- CLP(Z) adds a specialized solver for integers
- CLP(B), CLP(Q), CLP(R) and more

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Cyclic terms and occurs check

Occurs check

- Avoid terms of the form `A = f(A)`
- Supports rational trees (cyclic terms)
- Not checking is faster, but not right

Practical Prolog

- Some operations can fail:

```
A = 1 + A, B is A.
```

- Checks can be turned on:

```
set_prolog_flag(occurs_check, true).
```

Demo

Enabling occurs check

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Implementation structure

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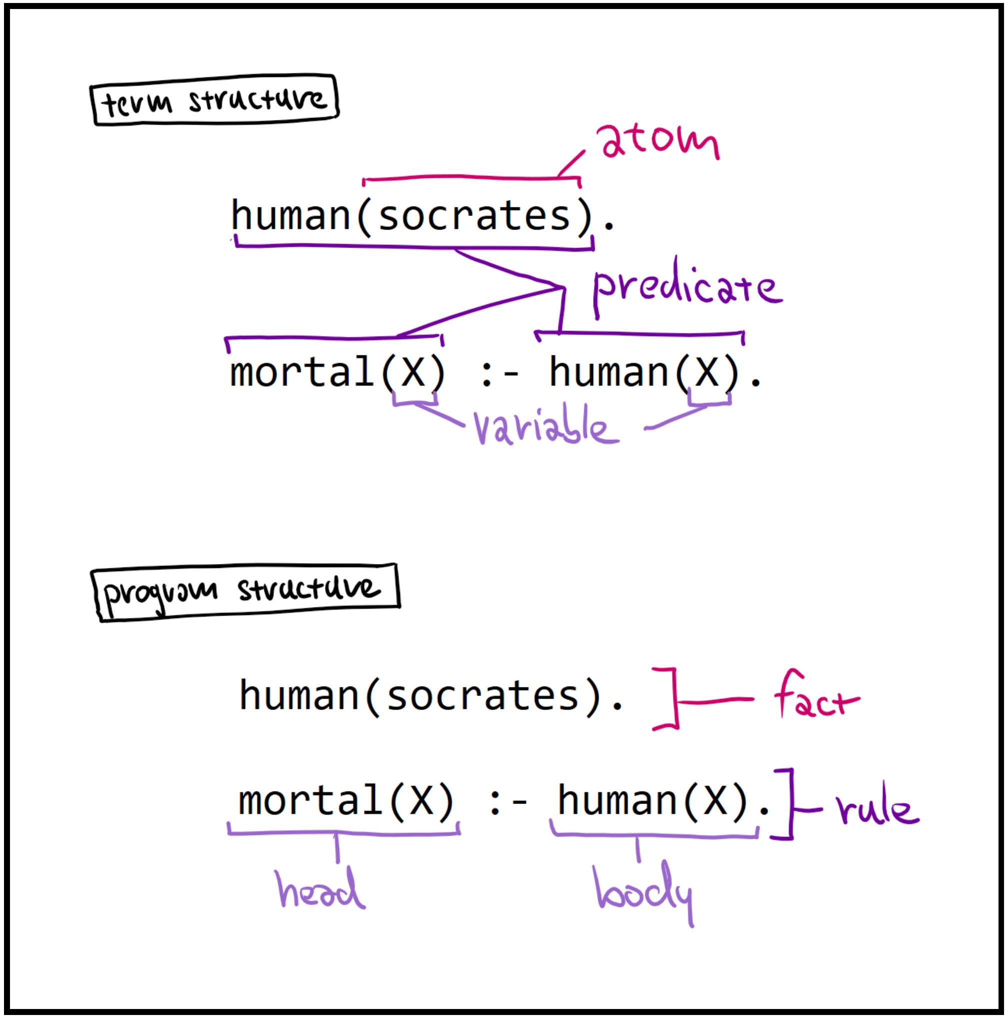

TinyProlog programs

Program is a list of clauses which are:

1) Rules (head + body)
2) Facts (head)

A term can be:

1) Variable
2) Atom
3) Predicate

```
(* Recursive term definition *)
type Term =
  | Atom of string
  | Variable of string
  | Predicate of
      string * Term list
  | Call of Term * Term list

(* Facts have empty Body *)
type Clause =
  { Head : Term
    Body : Term list }

(* Create a fact clause *)
let fact p =
  { Head = p; Body = [] }

(* Create a rule clause *)
let rule p b =
  { Head = p; Body = b }
```

TinyProlog programs

Encoded as F# types!

Atom vs. variable

Atom is a single data item, thing that exists.

Variable is a place-holder that we want to assign a term to.

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Prolog resolution logic

- Start with user query as the goal
  Single (or multiple) term(s) with unbound variables
- Find applicable rule/fact by matching its head
  Unification to check if the rule can be applied
- Generate substitution from the matching
  Substitution generated by unification process
- Add goals based on the rule body
  Apply substitution and repeat until all goals solved

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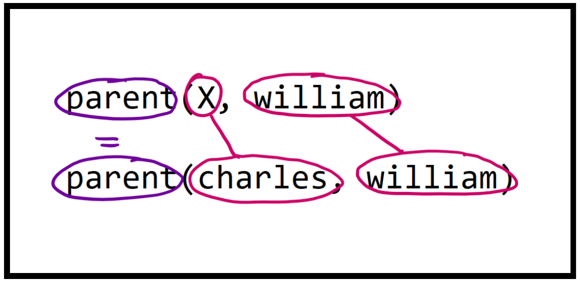
The unification process

Tiny implementation

- Similar to our type inference code!
- **`unify`** and **`unifyLists`** functions
- Generate substitution for variables



Used in Prolog context

- Same 2 uses of substitution
- Occurs check done optionally
- Use fresh set of variables when reusing rules from program database!

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Unification logic

```
let rec unifyLists l1 l2 =
  match l1, l2 with
  | [], [] ->
      (* empty substitution*)
  | h1::t1, h2::t2 ->
     match unify h1 h2 with
     | Some(s) -> (*
        1. substitution 's' to
           unify 'h1' and 'h2'
        2. now unifiy 't1' and 't2'
           recursively & compose
        3. if not possible, fail *)
     | _ -> (* fail *)
  | _ -> (* fail *)

and unify t1 t2 =
  match t1, t2 with
  | Atom(a1), Atom(a2) -> (* does 'a1' match 'a2'? *)
  | Variable(v), t | t, Variable(v) ->
      (* return a substitution *)
  | Predicate(p1, args1), Predicate(p2, args2) ->
      (* if p1 = p2, unify arguments recursively *)
  | _ -> None
```

Split into two functions for better readability

`unify` matches terms

`unifyLists` matches two lists using **`unify`**

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Adding support for numbers and lists

```
% Number: 0
zero

% Number: 1
one = s(zero)

% Number: 5
five = s(s(s(s(s(zero)))))

% Empty list
empty

% List [1]
cons(one, empty)

% List [1; 5]
cons(one, cons(five, empty))
```

Nothing extra is needed!

Good enough for a tiny implementation.

Terribly inefficient and limited if you want to calculate anything!

The F# language

Useful advanced features

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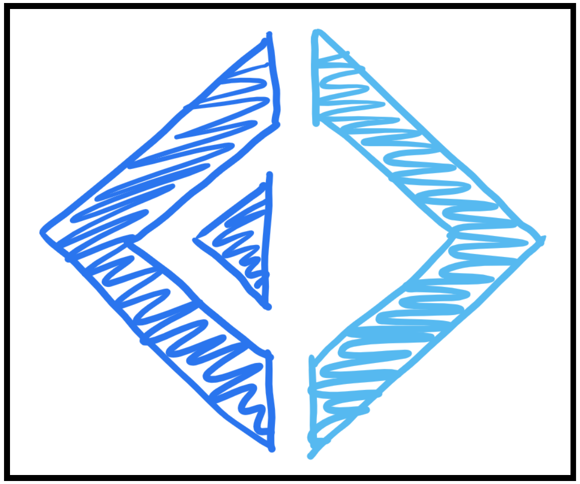
Advanced F# features

Active patterns

- Custom patterns for use in **`match`**
- Match number with **`Odd`** or **`Even`**
- Recognize special forms of terms
- Complete or partial patterns



Sequence expressions

- Write code that generates a sequence of items
- Comprehensions (Haskell), generators (JS), ...
- Lazy **`seq {..}`** or eager `[..]` or arrays `[|..|]`

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Demo

Advanced F# features

Lab overview

TinyProlog system step-by-step

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TinyProlog - Basic tasks

1. Implementing basic unification of terms
   Recursively match atoms, variables and predicates
2. Composing and applying substitutions
   To handle multiple occurrences of a variable correctly
3. Searching clauses & variable renaming
   Find applicable rules and relevant facts in program
4. Generating and proving goals recursively
   The key trick! Generate and solve goals in a loop
5. Adding numbers to TinyProlog
   Representing, calculating and pretty printing

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TinyProlog - Bonus and super tasks

1. **Lazy search and support for lists**
   Refactoring for readability and more pretty printing
2. **Generating magic squares in TinyProlog**
   In which we find out how slow our implementation is :-)
3. **Implementing call and functional maplist**
   Adding special predicate for higher-order programming
4. **Adding support for occurs checks**
   If you want to make it slower and more correct
5. **Implementing Prolog-style cut operator**
   Super-bonus if you are into Prolog programming...

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Closing

A tiny logic programming language

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Conclusions

A tiny declarative logic programming language

- Remarkably similar to ML type inference!
- This is not a coincidence...
- Evaluation as search, not a sequence of steps
- Much work needed to make this practical

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