Telescoping Languages

or High Performance Computing for Dummies

Arun Chauhan

Rice University

Two True Stories

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  - almost everyone uses MATLAB
  - a large number uses MATLAB exclusively
  - almost everyone hates writing C code
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  - often forced to rewrite programs in C
- linear algebra through MATLAB
  - ARPACK—a linear algebra package to solve eigenvalue problems
  - prototyped in MATLAB
  - painfully hand translated to FORTRAN

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- performance problems limit their use
- the productivity connection

History Repeats

"It was our belief that if FORTRAN, during its first months, were to translate any reasonable 'scientific' source program into an object program only half as fast as its hand-coded counterpart, then acceptance of our system would be in serious danger... I believe that had we failed to produce efficient programs, the widespread use of languages like FORTRAN would have been seriously delayed." *–John Backus*

Pushing the Level Again

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Fundamental Observation

- libraries are the key in optimizing high-level scripting languages

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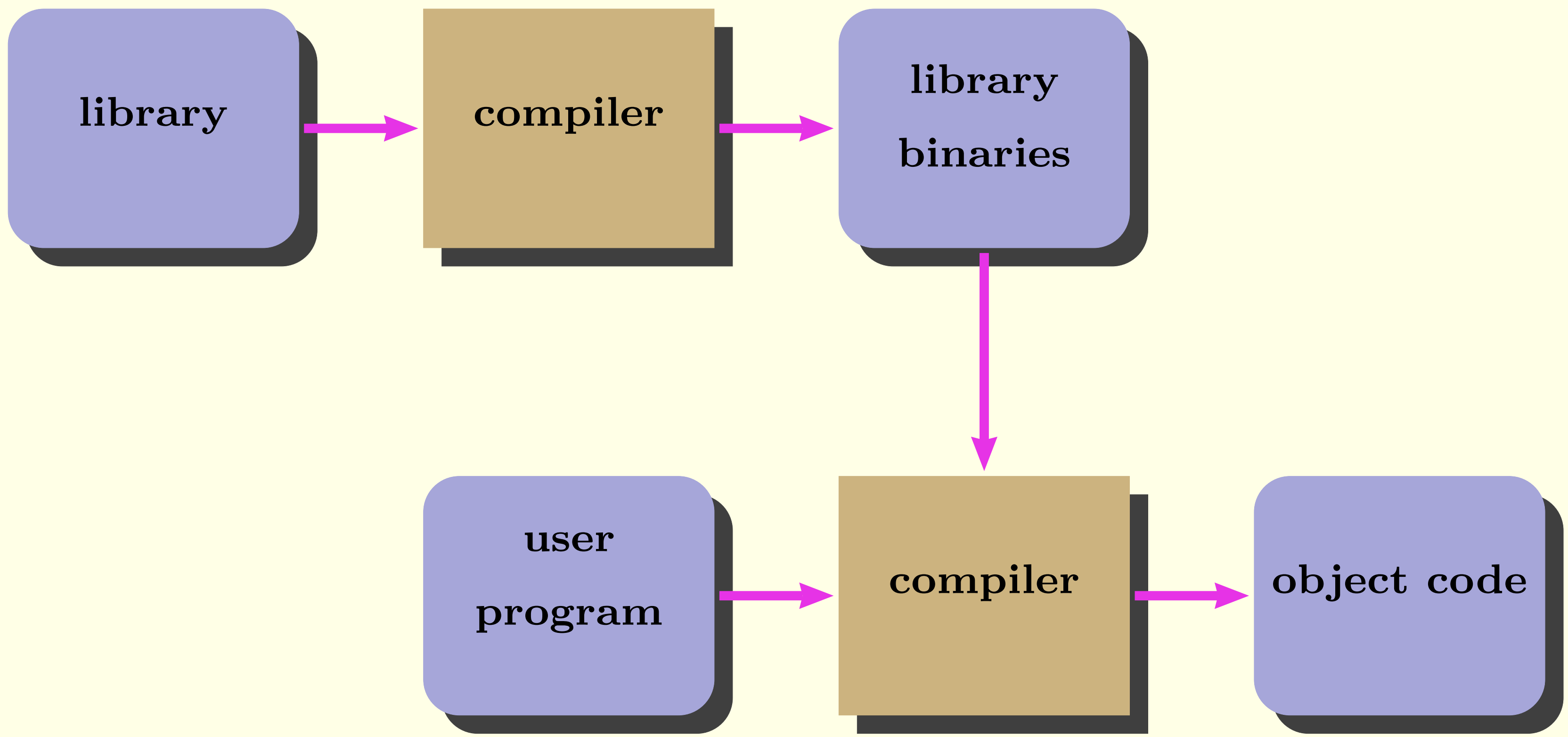
  `a = x * y` $\Rightarrow$ `a = MATMULT(x, y)`

- libraries **are** high-level languages!
  - a large effort in HPC is towards writing libraries
  - domain-specific libraries make scripting languages useful and popular
  - high-level operations are largely "syntactic sugar"

Libraries as Black Boxes



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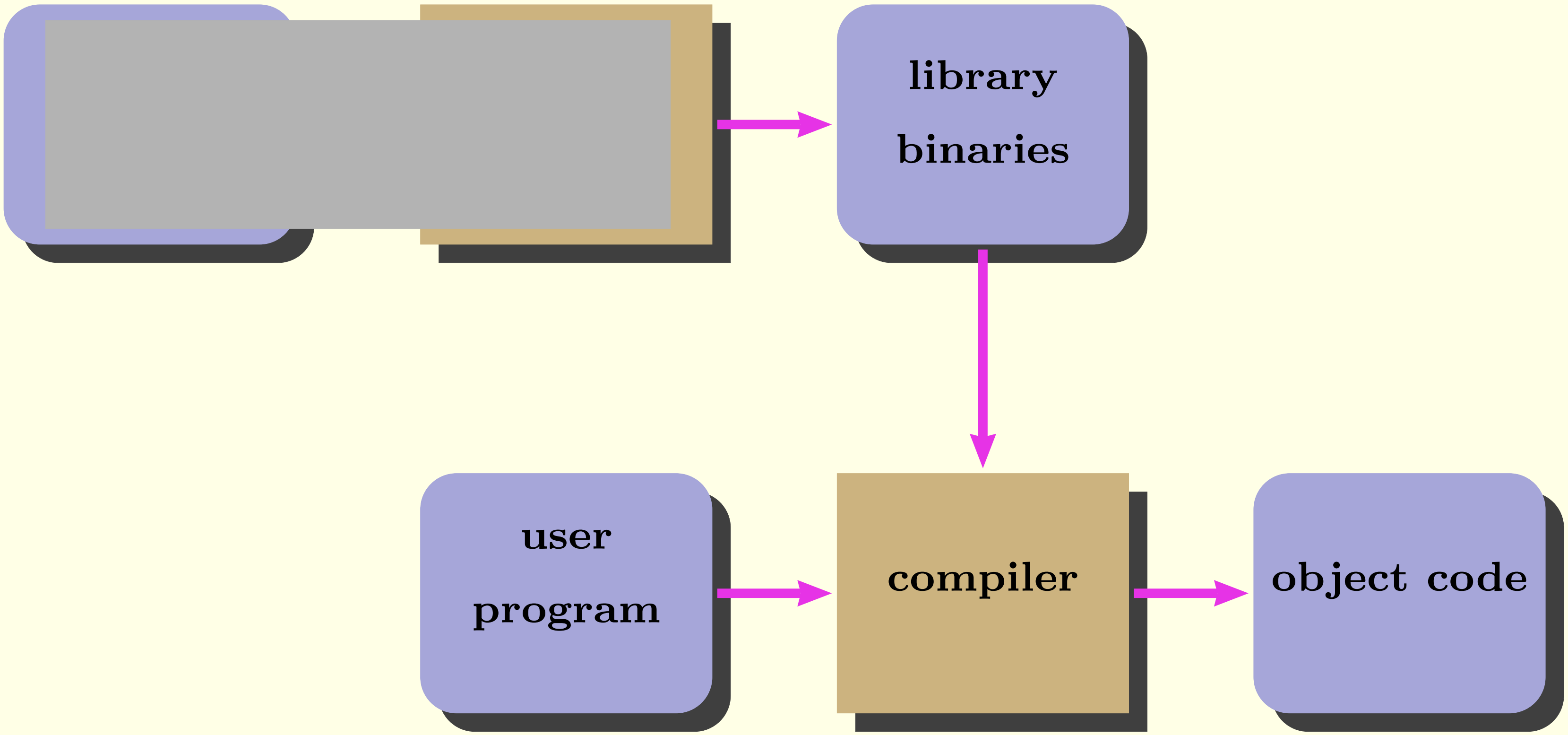
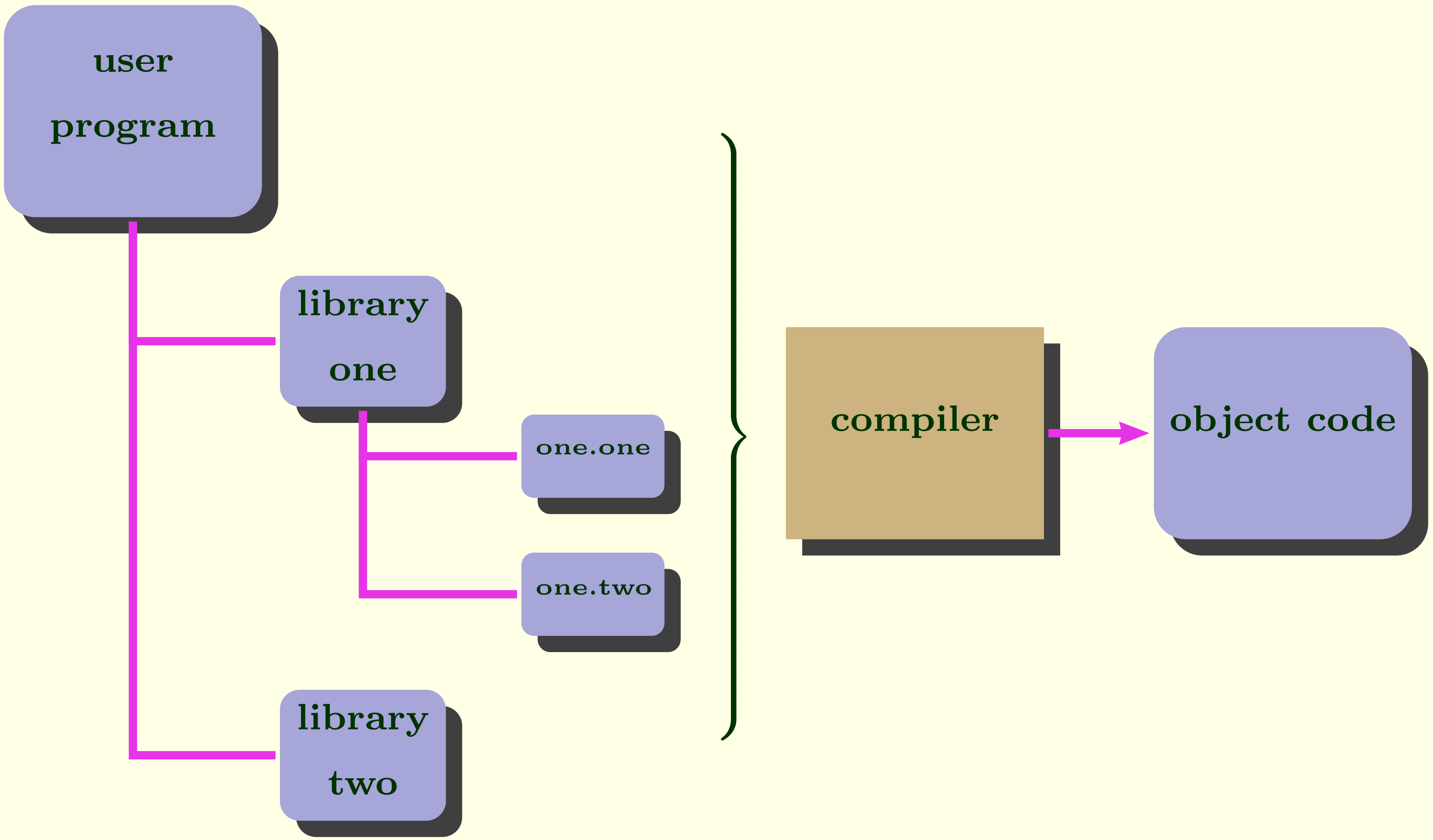


Whole Program Compilation



Telescoping Languages Approach

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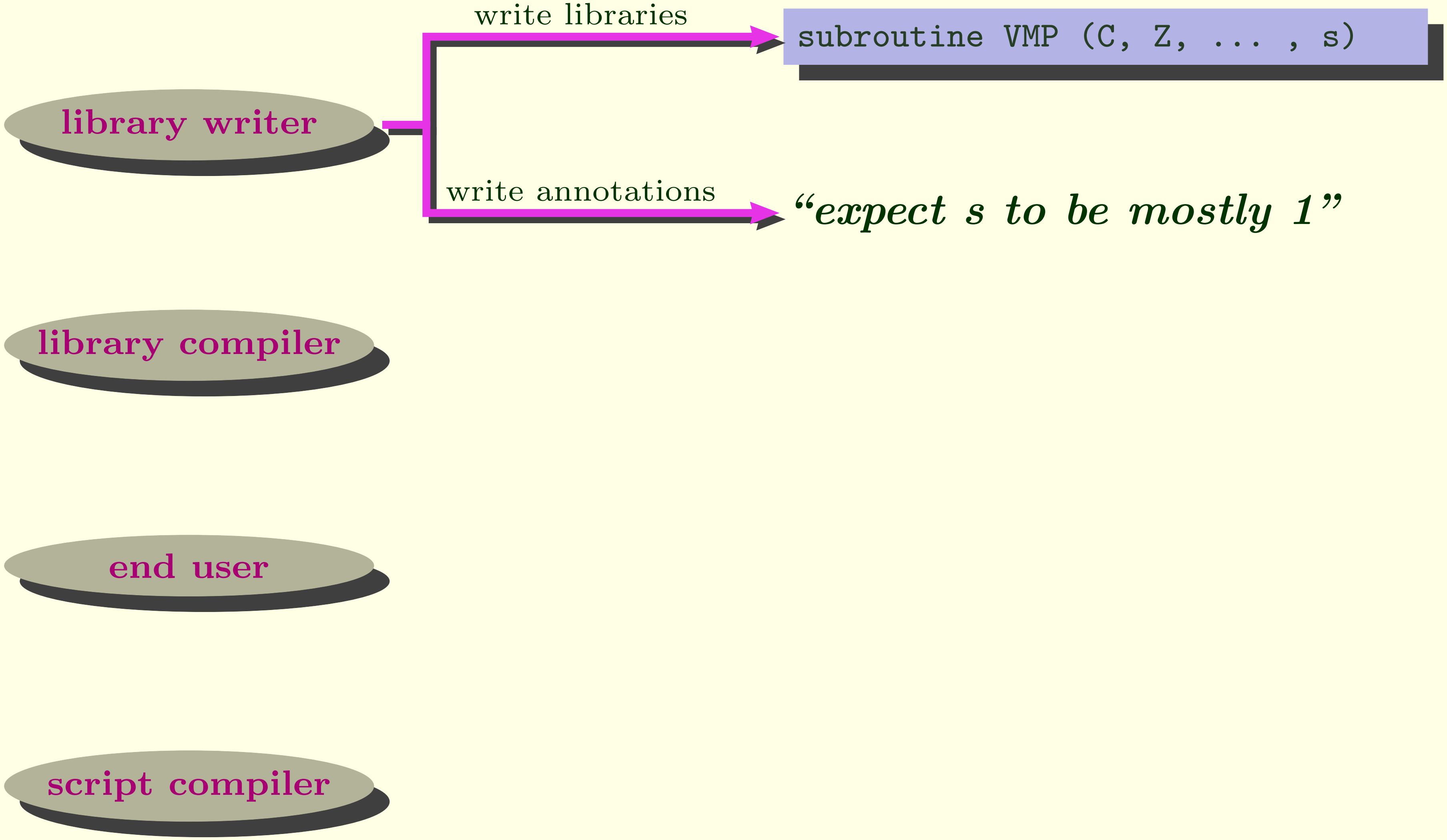
analogous to offline indexing by search engines

Telescoping Languages: Entities

- library writer
- library compiler
- end user
- script compiler

Telescoping Languages: Entities



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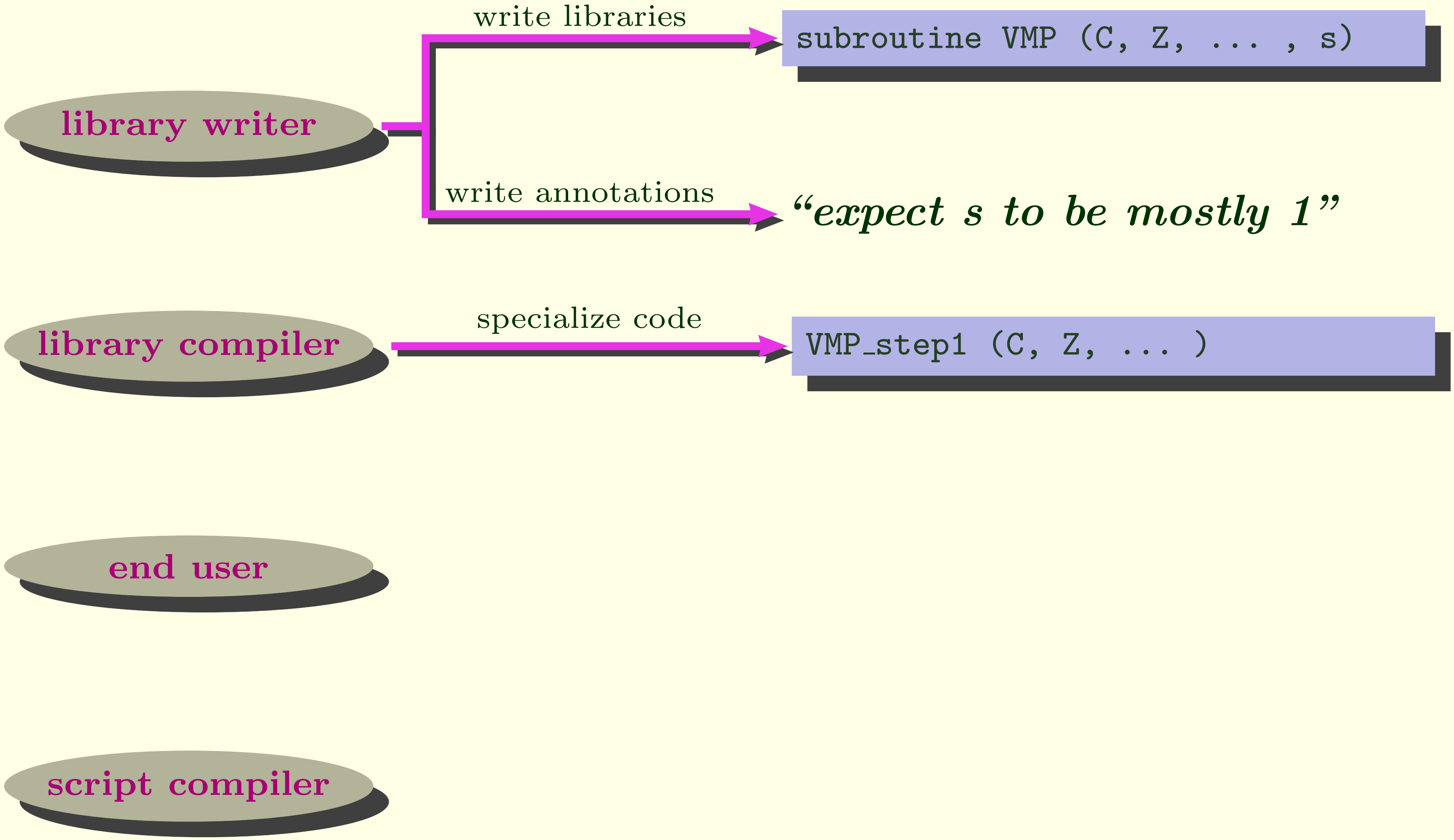

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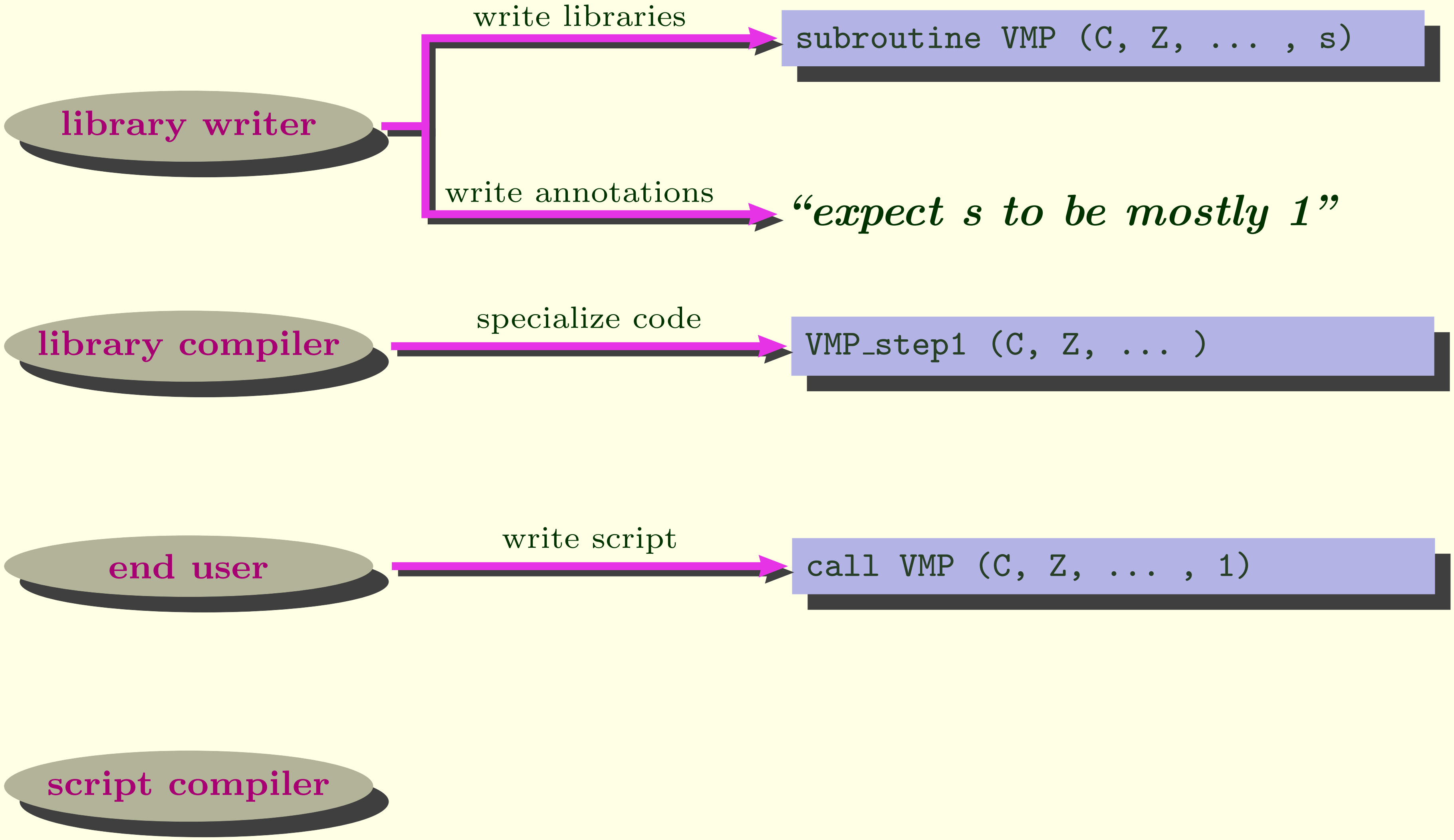

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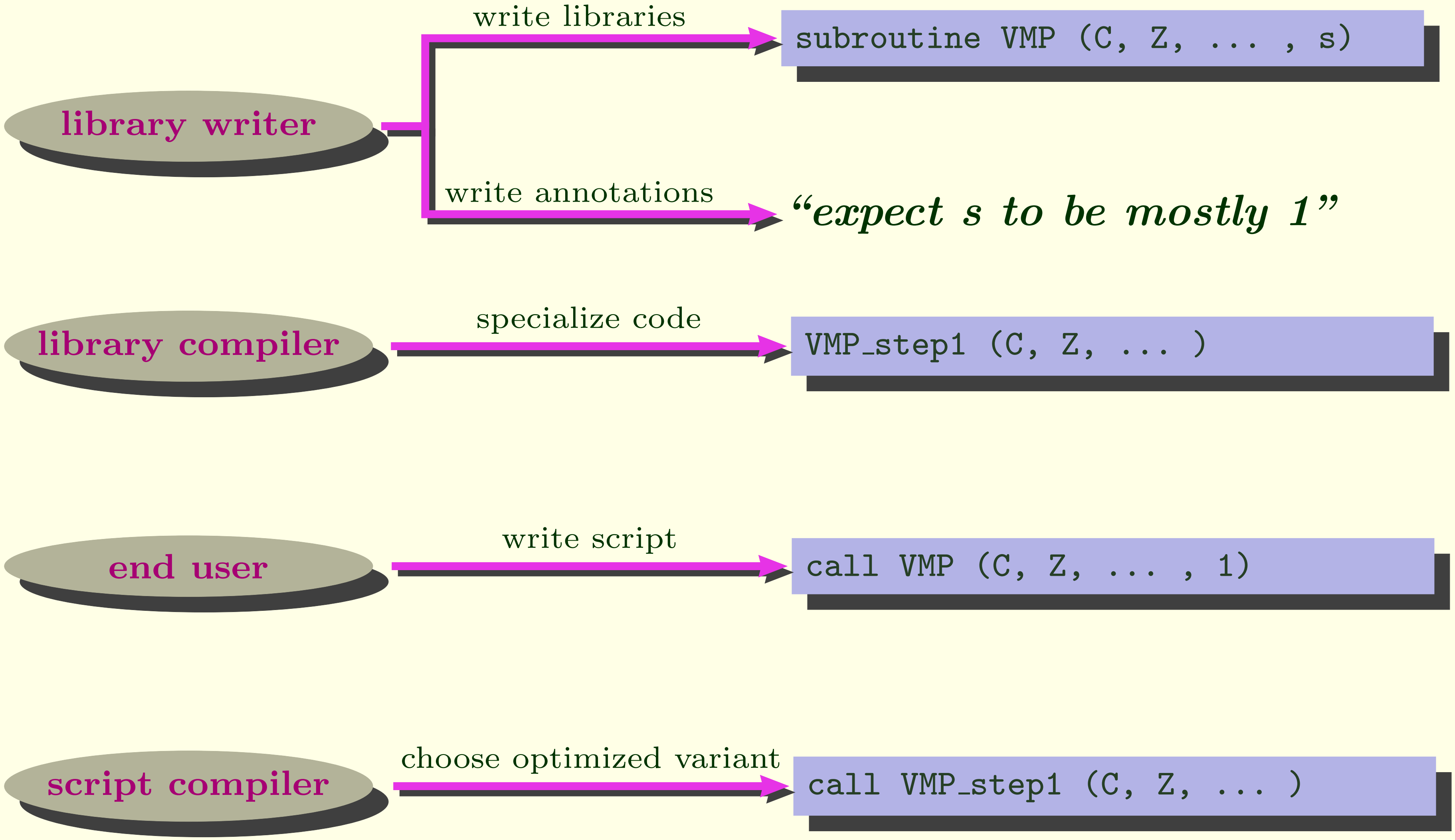

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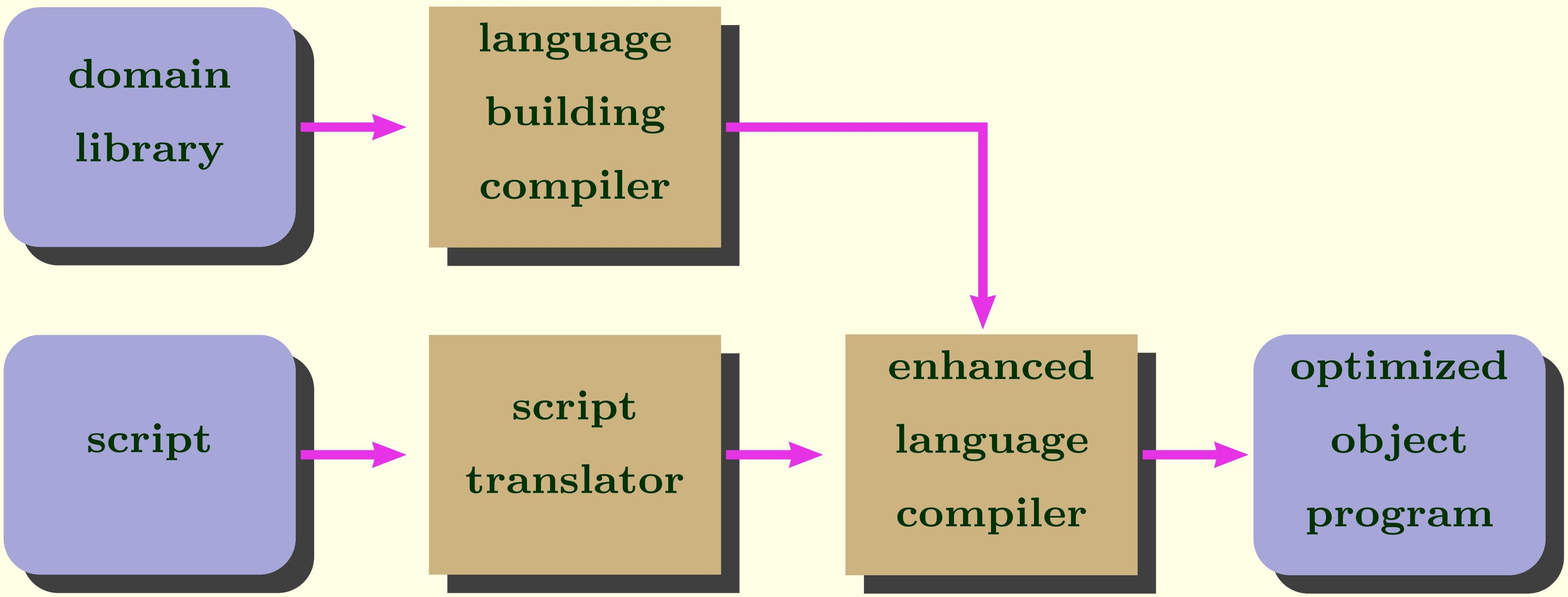

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  - which kinds of specializations
  - how many
- identifying high pay-off optimizations
  - must be applicable in telescoping languages context
  - should focus on these first
- enabling the library writer to express these transformations
  - guide the specialization
  - describe equivalences (identities)

Example from ARPACK

```
function [V,H,f] = ArnoldiC (A,k,v);
    n = length(v);
    H = zeros(k);
    V = zeros(n,k);
    v = v/norm(v);
    w = A*v;
    alpha = v'*w;
    ...
    for j = 2:k,
        beta = norm(f);
        v = f/beta;
        ...
    end
```

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Inferring Types

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- type $\equiv <\tau, \delta, \sigma, \psi>$
  - τ = intrinsic type, e.g., int, real, complex, etc.
  - δ = array dimensionality, 0 for scalars
  - σ = δ-tuple of positive integers
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- type inference in general
  - variable type = the "largest" set of values that preserves meaning
- type inference for type-based specialization
  - **all valid configurations** of types are needed

Formulating the Problem
(joint work with Cheryl McCosh)

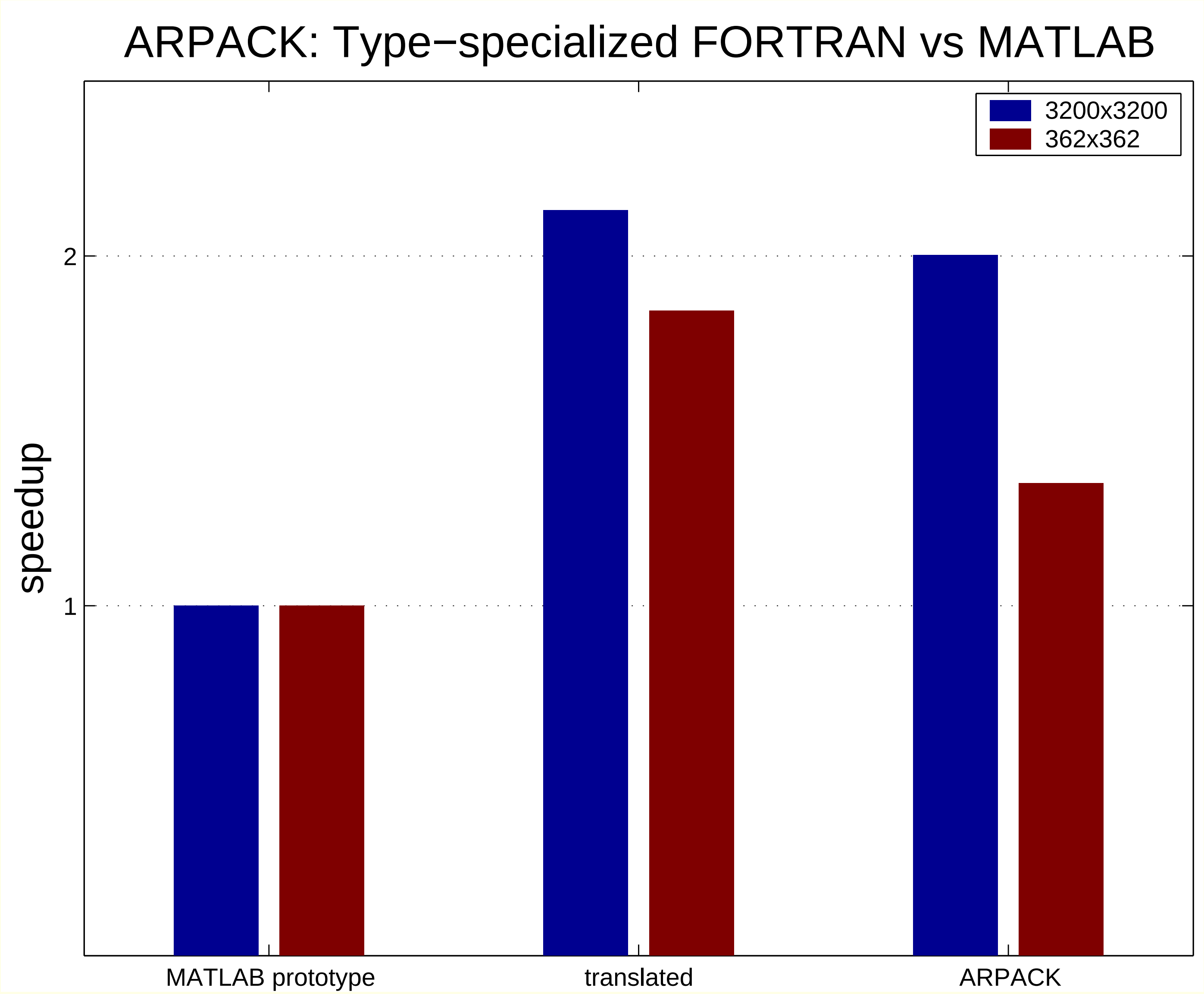
```
v = v/norm(v);
w = A*v;
```

- each operation or function call imposes certain "constraints" on the types of its arguments and return values
- the type of a variable is the "smallest" one that meets all the constraints
- incomparable types may give rise to multiple valid configurations of variable types

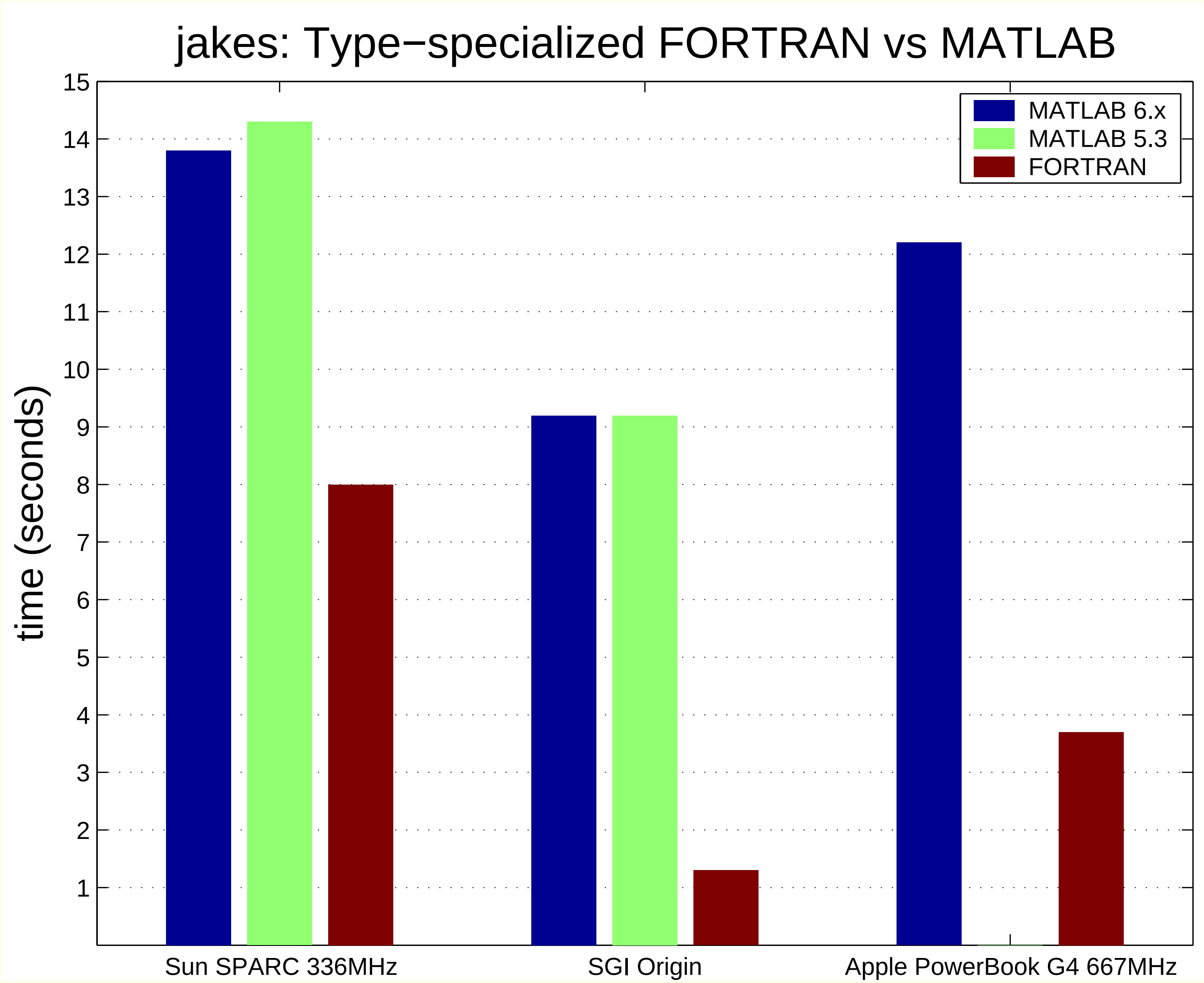
Solving the Problem

- the problem is hard to solve in general
- efficient solution is possible under certain conditions
- the idea is to reduce it to the clique problem
  - a constraint defines a level
  - clauses in a constraint are nodes at that level
  - an edge whenever two clauses are "compatible"
  - a clique defines a valid type configuration
- some type information must still be inferred dynamically
  - novel technique called **slice hoisting**

Results: ARPACK



Experimental Evaluation



Moving Beyond

- study of DSP applications
- library identities play a key role
- identified high-payoff well-known optimization techniques
  - vectorization caused 33 times speedup in one case!
  - others: common subexpression elimination, constant propagation, beating and dragging along
- discovered two novel optimizations
  - procedure strength reduction
  - procedure vectorization

Procedure Strength Reduction

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```
for i = 1:N
    ...
    f (c1, c2, i, c3);
    ...
end
```

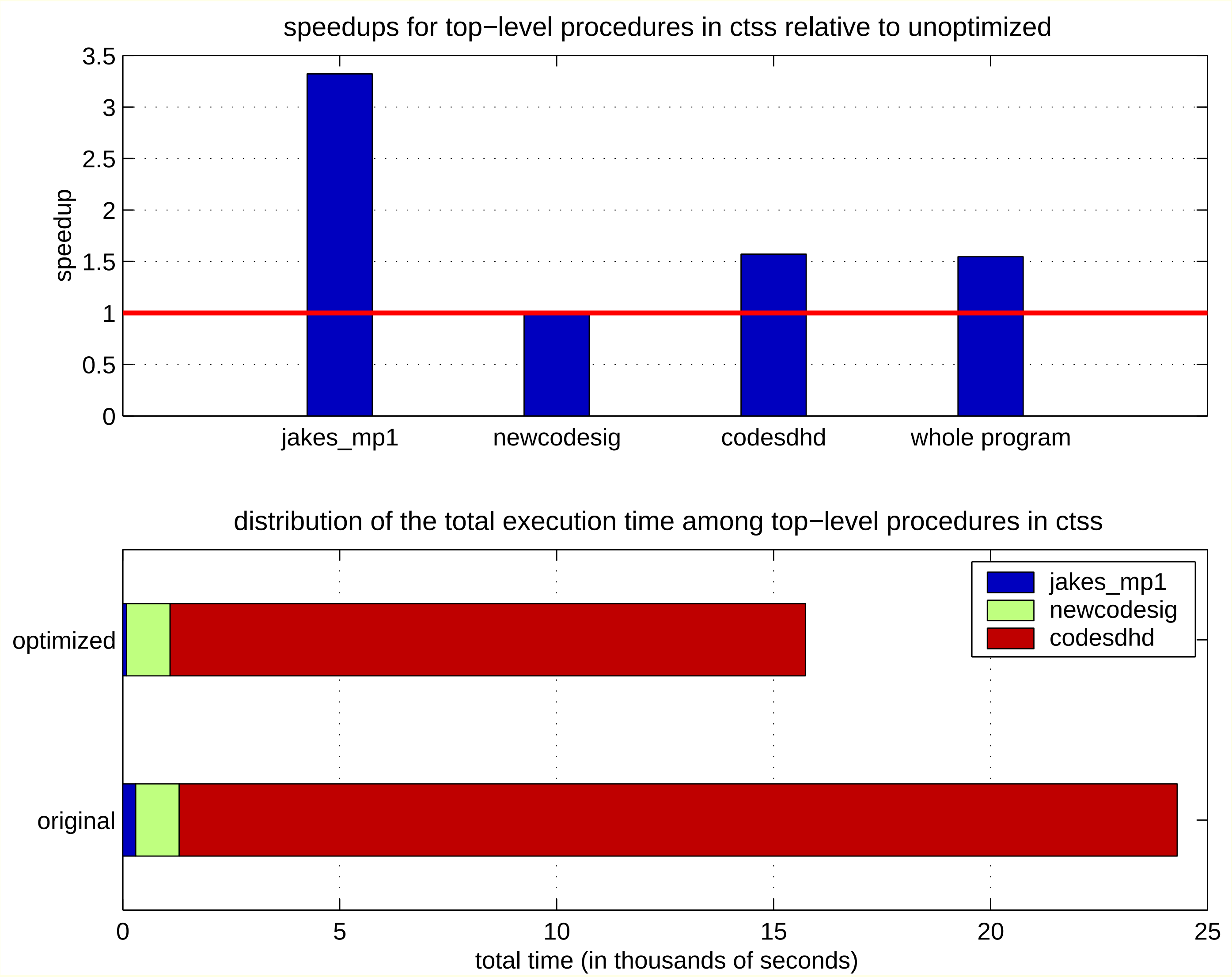
Procedure Strength Reduction

```
for i = 1:N
   ...
   f (c1, c2, i, c3);
   ...
end
```

→

```
f_init (c1, c2, c3);
for i = 1:N
   ...
   f_iter (i);
   ...
end
```

Experimental Evaluation



Contributions

- demonstrating the viability of scripting languages for library generation through the telescoping languages approach
- specific technical contributions
  - identification of high-payoff optimizations
  - discovery of two new optimizations
  - development of a novel type-inference algorithm
- telescoping infrastructure
  - MATLAB compiler with C / FORTRAN library generator

Future Directions

- annotation language to describe transformations
- techniques to speculatively optimize code
  - database techniques
- time and space trade-offs in library generation
  - AI techniques
- applying the ideas to automatic parallelization
- dynamically evolving systems like the computation grid
- other domains
  - VLSI design

Past Work

- runtime execution model for irregular parallel applications
- parallelization techniques for high performance multimedia applications
- algorithmic techniques for parallel Cholesky factorization on SMP
- parallelization of weather forecasting application for an SMP

Conclusion

- need to make a move towards high-level languages for high-performance computing
- telescoping languages provide the compiler technology to enable this move
- type-based speculative specialization a primary step
- a novel type-inference algorithm enables this step
- identified high-payoff optimizations
- discovered two new optimizations

`http://www.cs.rice.edu/~achauhan/`

Bonus Material

Procedure Vectorization

Procedure Vectorization

```
for i = 1:N
    f (c_1, c_2, i, A[i]);
end
...
function f (a_1, a_2, a_3, a_4)
    <body of f>
```

Procedure Vectorization

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for i = 1:N
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```

→

```
f_vect (c1, c2, [1:N], A)
...
function f_vect (a1, a2, a3, a4)
    for i = 1:N
        <body of f>
    end
```