Procedure Strength Reduction: An Optimizing Strategy for Telescoping Languages

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Motivation

- High Performance programming is hard
  - Increasingly a specialized activity
  - Shortage of programmers
- Enable end−users to program
  - Language should be high level
  - Should provide domain−specific features
  - Must have effective and efficient compilers

Current Scenario

- Object Oriented Languages
  - Targeted towards professionals
  - Still not sufficiently high−level for end−users
- Functional Programming Languages
  - Suffer from performance problems
- Scripting Languages (e.g., Matlab)
  - Preferred and used by end−users
  - Have domain specific libraries
  - But, no fast and effective compilers

Key Problems

- Libraries treated as black boxes
  - no library source code

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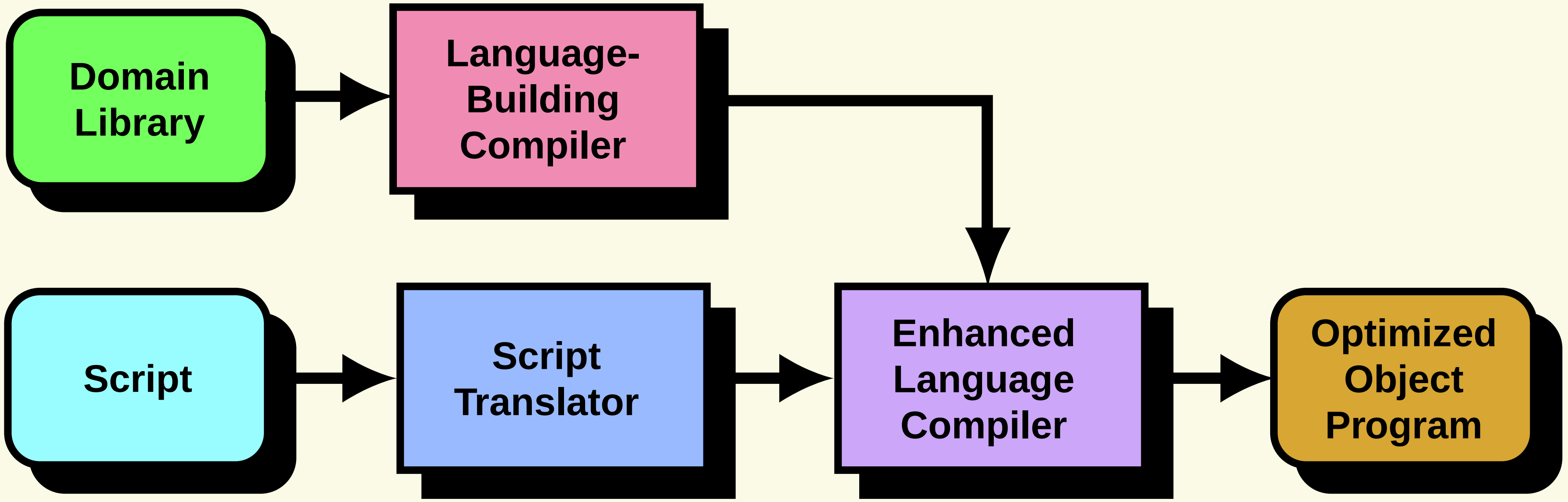
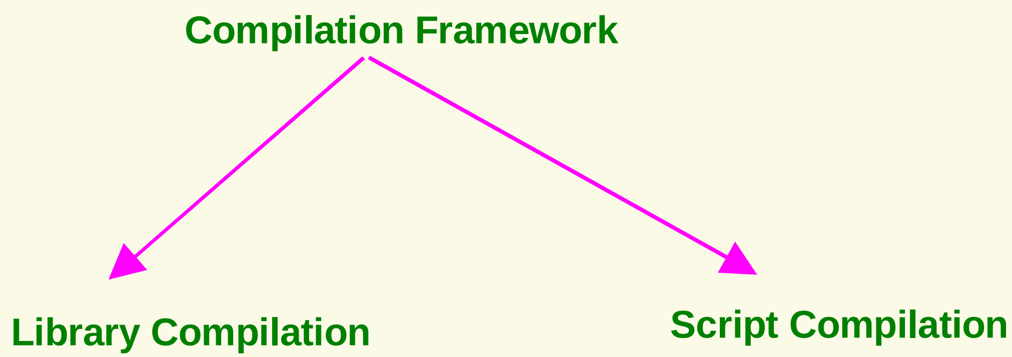
- Libraries treated as black boxes
  - no library source code
- Translation to conventional languages
  - potentially very high compilation times
- Expert knowledge on libraries discounted
  - potential optimization opportunities lost

Telescoping Languages Approach



Compiling Telescoping Languages



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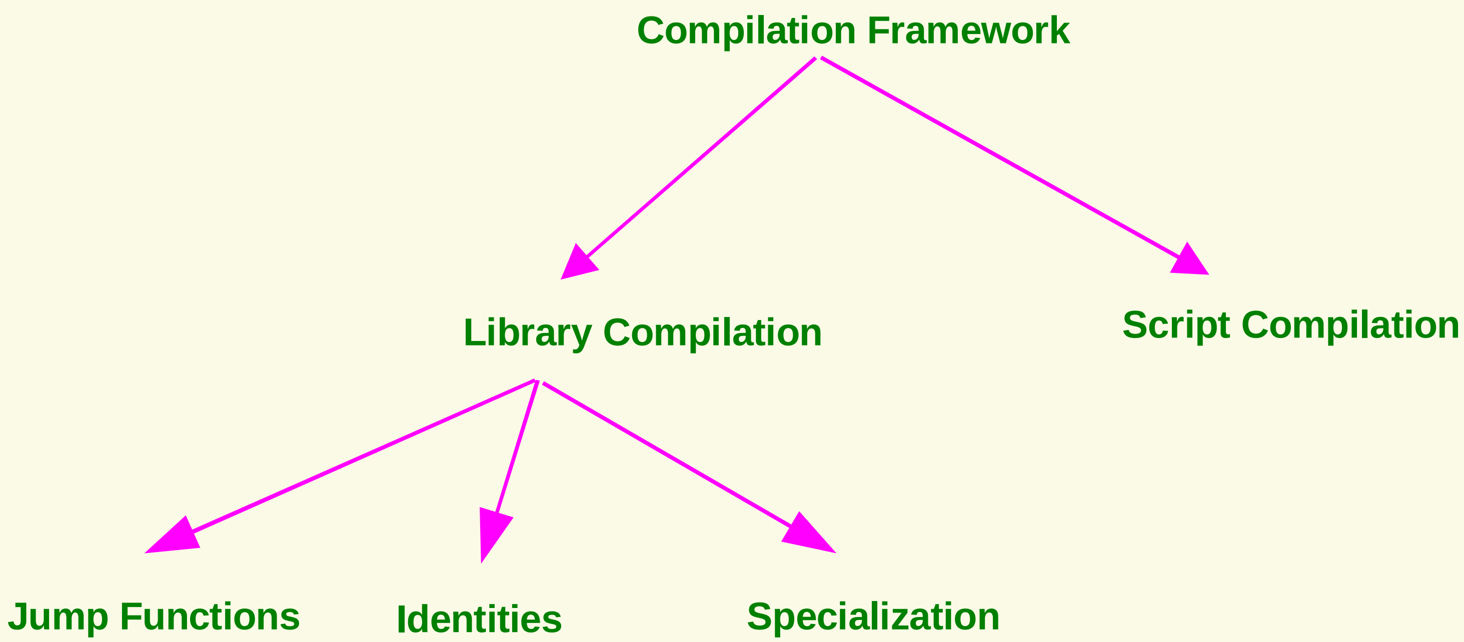

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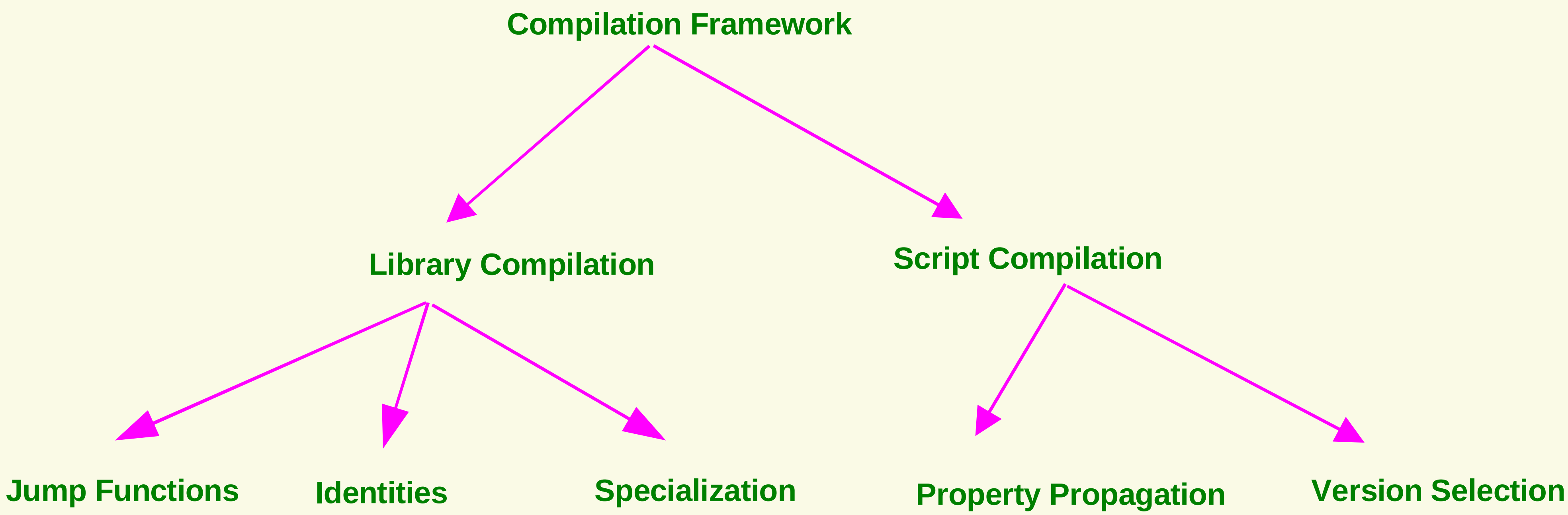

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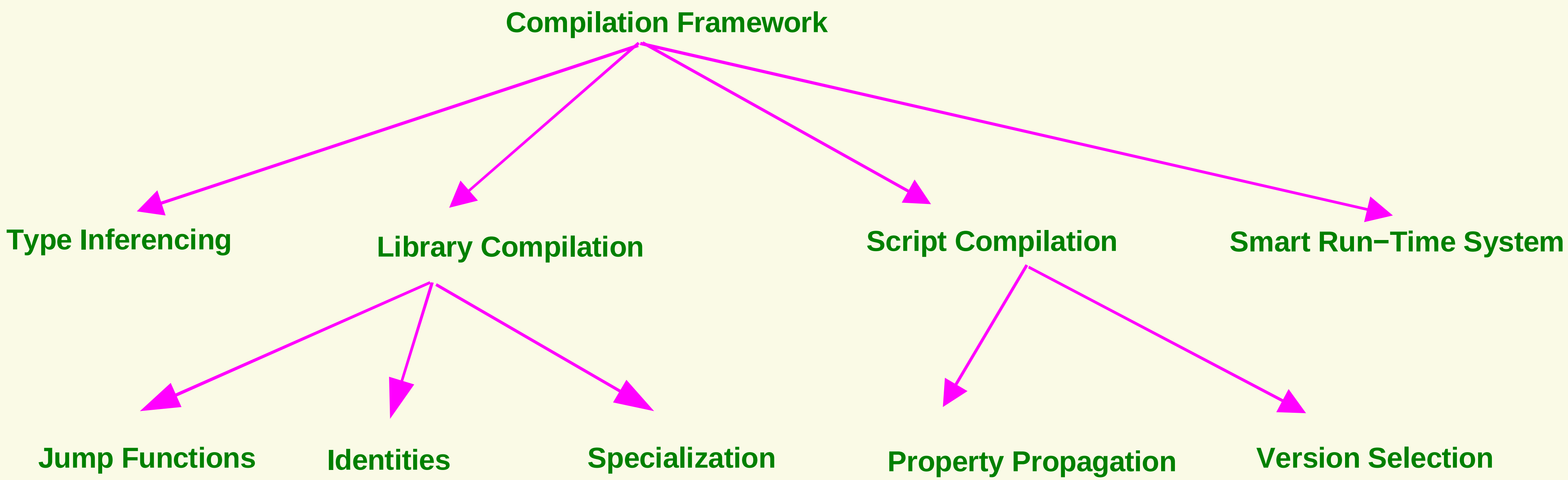

Example Codes

- Real DSP codes used by ECE wireless group
- Long Running codes, potential for optimization
- Written in Matlab (even though slow)
- Parts of the codes re−used extensively (candidates for domain−specific lib routines)

Useful Optimizations: Vectorization

```
function z = jakes_mp1 (blength, speed, bnumber, N_Paths)

....

for k = 1:N_Paths

  ....



  for j = 1 : Num
     xc(j) = s
     qrt(2) * cos (omega * t_step * j);
     xs(j) = 0;
     for n = 1 : Num_osc
         cosine = cos(omega * cos(2 * pi * n / N) * t_step * j);
         xc(j) = xc(j) + 2 * cos(pi * n / Num_osc) * cosine;
         xs(j) = xs(j) + 2 * sin(pi * n / Num_osc) * cosine;
     end
  end

  ....

end
```

Useful Optimizations: Vectorization

```
function z = jakes_mp1 (blength, speed, bnumber, N_Paths)

....

for k = 1:N_Paths

   ....
   xc = sqrt(2)*cos(omega*t_step*j’) ...
        + 2*sum(cos(pi*np/Num_osc).*cos(omega*cos(2*pi*np/N)*t_step.*jp));
   xs = 2*sum(sin(pi*np/Num_osc).*cos(omega*cos(2*pi*np/N)*t_step.*jp));

  %for j = 1 : Num
  %   end
  %   xc(j) = s
  %   qrt(2) * cos (omega * t_step * j);
  %   xs(j) = 0;
  %   for n = 1 : Num_osc
  %       cosine = cos(omega * cos(2 * pi * n / N) * t_step * j);
  %       xc(j) = xc(j) + 2 * cos(pi * n / Num_osc) * cosine;
  %       xs(j) = xs(j) + 2 * sin(pi * n / Num_osc) * cosine;
  %   end
  %end

   ....

end
```

Useful Optimizations: CSE

```
function z = jakes_mp1 (blength, speed, bnumber, N_Paths)

....

for k = 1:N_Paths

  ....
  xc = sqrt(2)*cos(omega*t_step*j’) ...
       + 2*sum(cos(pi*np/Num_osc).*cos(omega*cos(2*pi*np/N)*t_step.*jp));
  xs = 2*sum(sin(pi*np/Num_osc).*cos(omega*cos(2*pi*np/N)*t_step.*jp));


  ....

end
```

Useful Optimizations: Preallocation

```
function z = mdlOutputs (K, N, L, D, sprd_type, sprd_codes)

....


for ii = 1:L

    ....

    U_ii(ii,:,:) = zeros(N, 2*(N+1)*K)
    for user_i = 1:K
        for chip_i = 1:N
            U_ii(ii,:,....) = ....
        end
    end

    ....

end
```

Useful Optimizations: Preallocation

```
function z = mdlOutputs (K, N, L, D, sprd_type, sprd_codes)

....

U_ii(:,:,:) = zeros(L, N, 2*(N+1)*K)
for ii = 1:L

  ....

  % U_ii(ii,:,:) = zeros(N, 2*(N+1)*K)
  for user_i = 1:K
      for chip_i = 1:N
          U_ii(ii,:,....) = ....
      end
  end

  ....

end
```

Procedure Strength Reduction

- Procedure called inside loop
  - several arguments typically invariant
  - move invariant computations into init part
  - do incremental computations inside loop

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

Procedure Strength Reduction

- Procedure called inside loop
  - several arguments typically invariant
  - move invariant computations into init part
  - do incremental computations inside loop

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

→

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

Procedure Strength Reduction

```
....

for ii = 1:200
  chan = jakes_mp1 (16500, 160, ii, num_paths);

  ....

  for snr = 2:2:20
   ....
   [s,x,ci,h,L,a,y,n0] = ...
     newcodesig (NO, l, num_paths, M, snr, chan, sig_pow_paths);
   ....
   [o1,d1,d2,d3,mf,m]= codesdhd (y, a, h, NO, Tm, Bd, M, B, n0);
   ....
  end
end
....
```

Procedure Strength Reduction

```
....
jakes_mp1_init (16500, 160, num_paths);
for ii = 1:200
  chan = jakes_mp1_iter (ii);

  ....

  for snr = 2:2:20
   ....
   [s,x,ci,h,L,a,y,n0] = ...
     newcodesig (NO, l, num_paths, M, snr, chan, sig_pow_paths);
   ....
   [o1,d1,d2,d3,mf,m]= codesdhd (y, a, h, NO, Tm, Bd, M, B, n0);
   ....
  end
end
....
```

Procedure Vectorization

- Procedure called inside a loop
- Loop can be distributed around the call
  - interchange loop and call
  - vectorize the loop inside the procedure

Procedure Vectorization

```
....

for ii = 1:200
  chan = jakes_mp1 (16500, 160, ii, num_paths);

  ....

  ....

  for snr = 2:2:20
   ....
   [s,x,ci,h,L,a,y,n0] = ...
     newcodesig (NO, l, num_paths, M, snr, chan, sig_pow_paths);
   ....
   [o1,d1,d2,d3,mf,m]= codesdhd (y, a, h, NO, Tm, Bd, M, B, n0);
   ....
  end
end
....
```

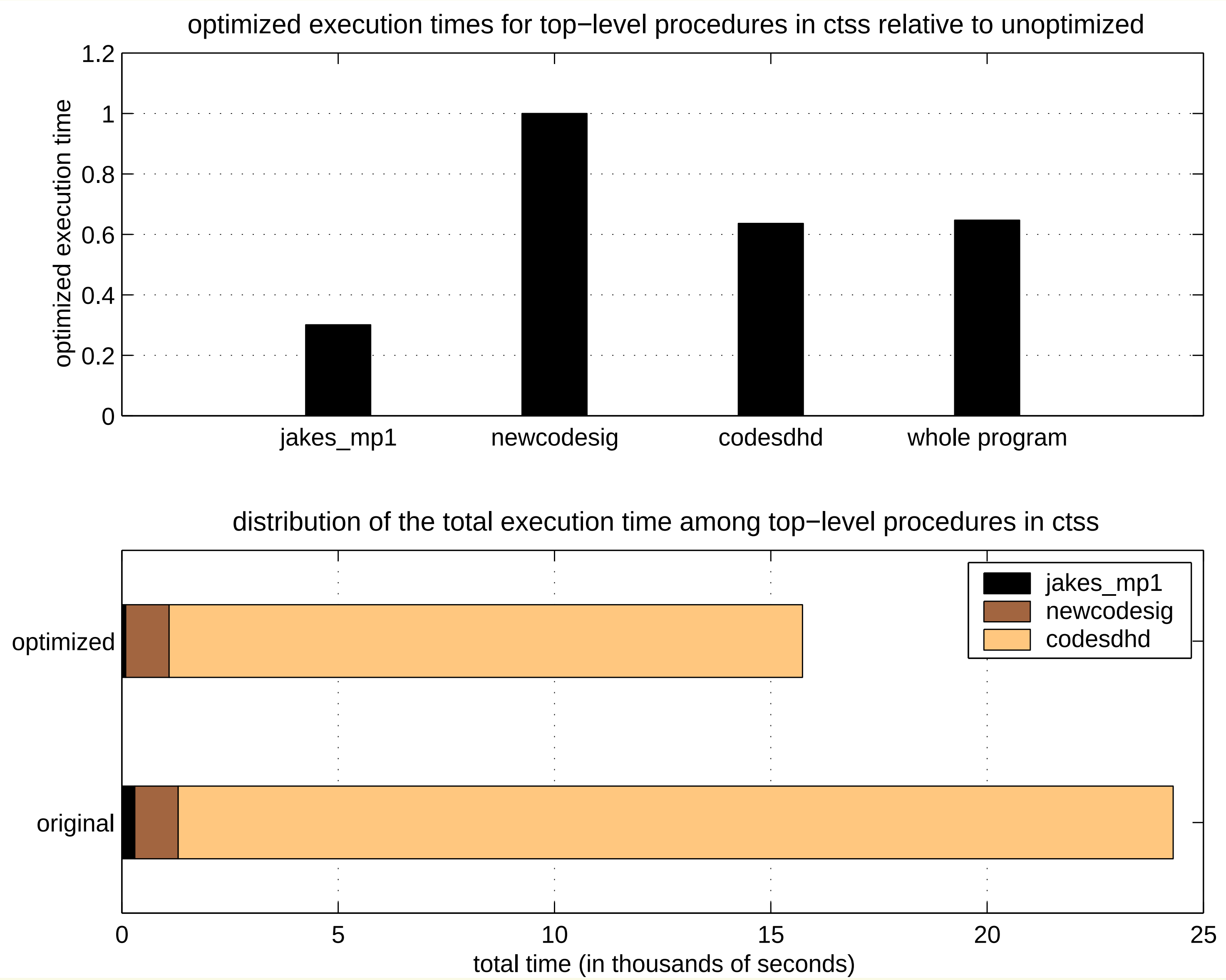
Procedure Vectorization

```
....

for ii = 1:200
  chan = jakes_mp1 (16500, 160, ii, num_paths);
end

for ii = 1:200
  ....

  for snr = 2:2:20
   ....
   [s,x,ci,h,L,a,y,n0] = ...
     newcodesig (NO, l, num_paths, M, snr, chan, sig_pow_paths);
   ....
   [o1,d1,d2,d3,mf,m]= codesdhd (y, a, h, NO, Tm, Bd, M, B, n0);
   ....
  end
end
....
```

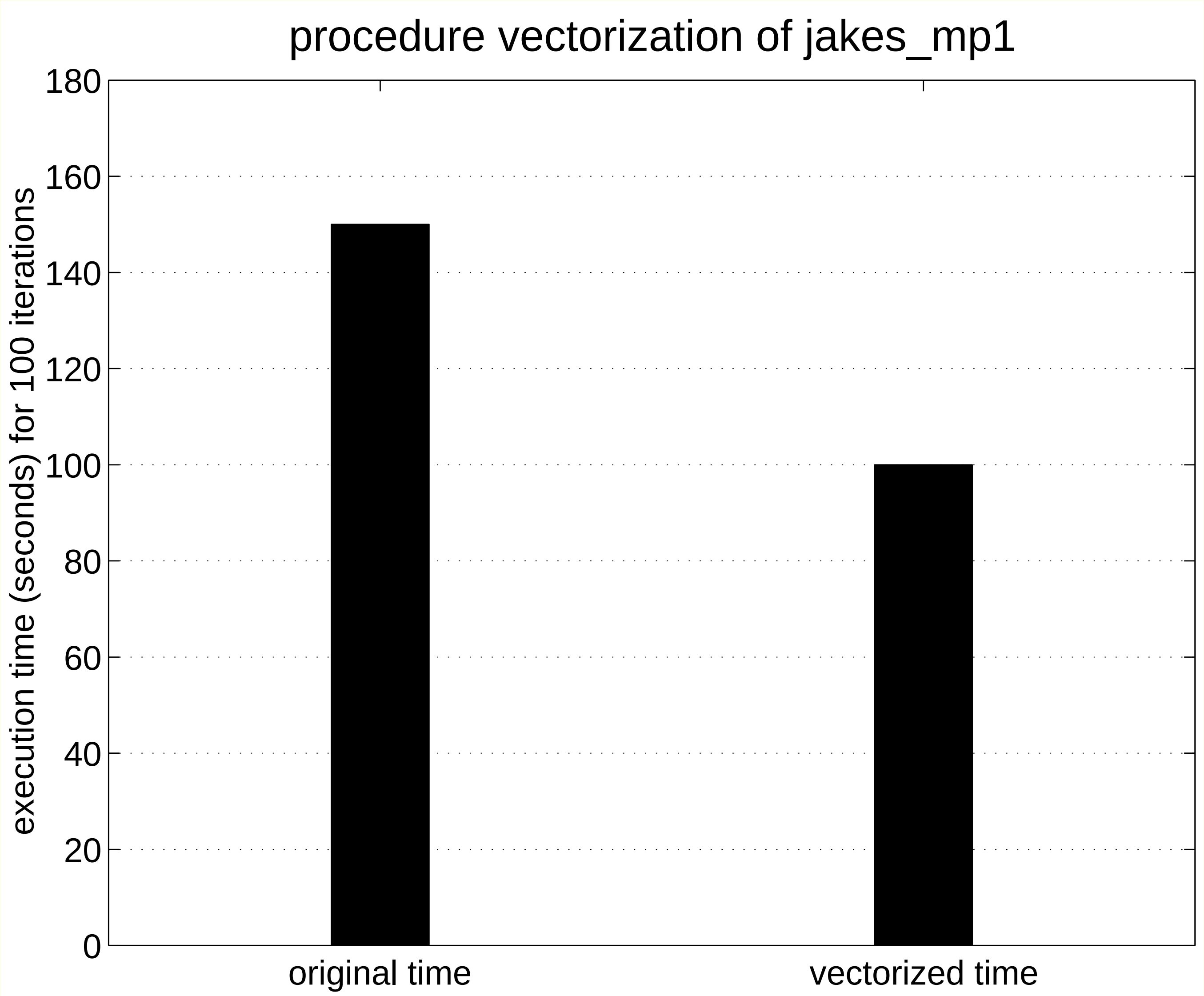
Procedure Vectorization

```
....


chan = jakes_mp1_vectorized (16500, 160, [1:200], num_paths);


for ii = 1:200
  ....

  for snr = 2:2:20
   ....
   [s,x,ci,h,L,a,y,n0] = ...
     newcodesig (NO, l, num_paths, M, snr, chan, sig_pow_paths);
   ....
   [o1,d1,d2,d3,mf,m]= codesdhd (y, a, h, NO, Tm, Bd, M, B, n0);
   ....
  end
end
....
```

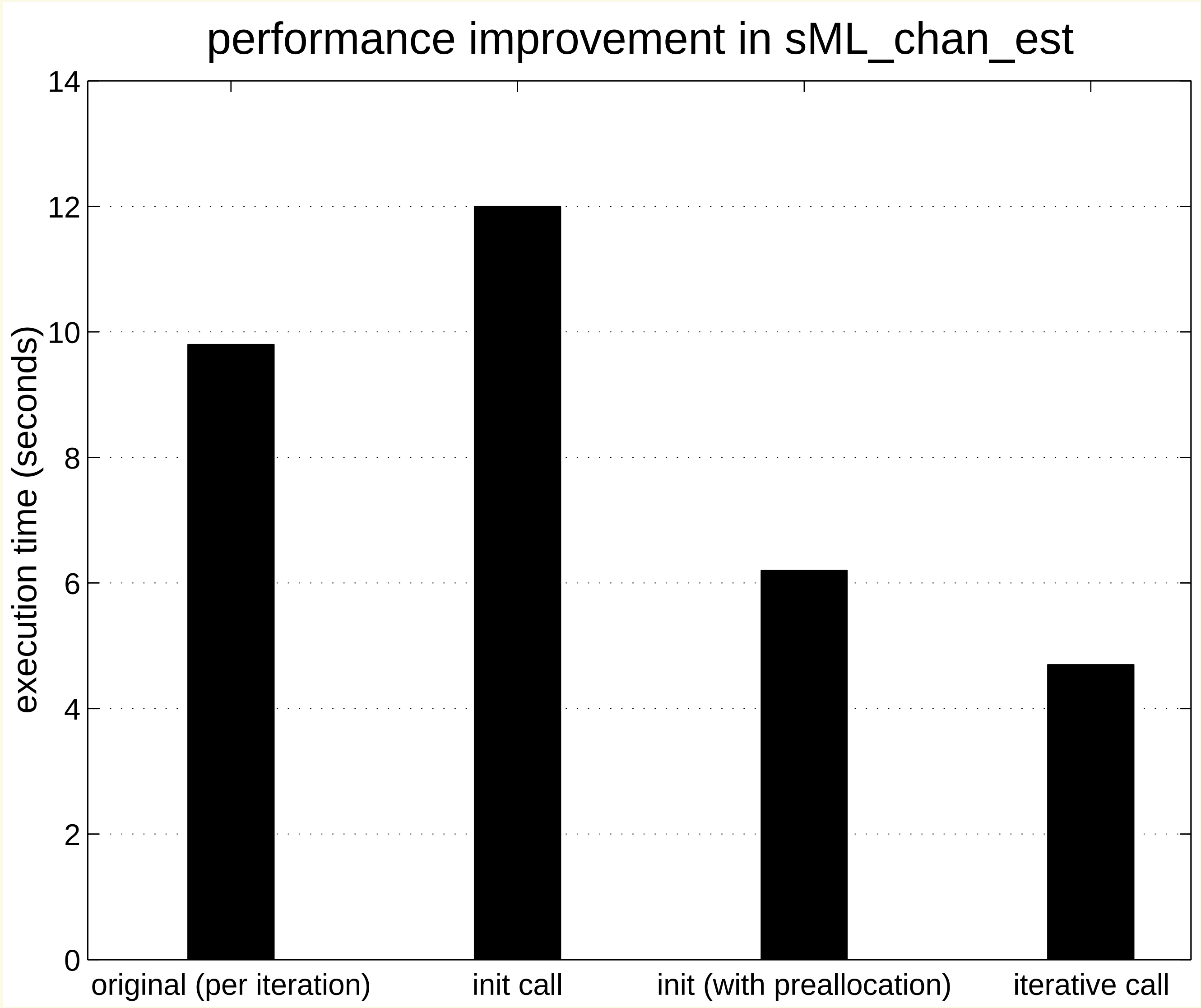
ctss: strength reduction



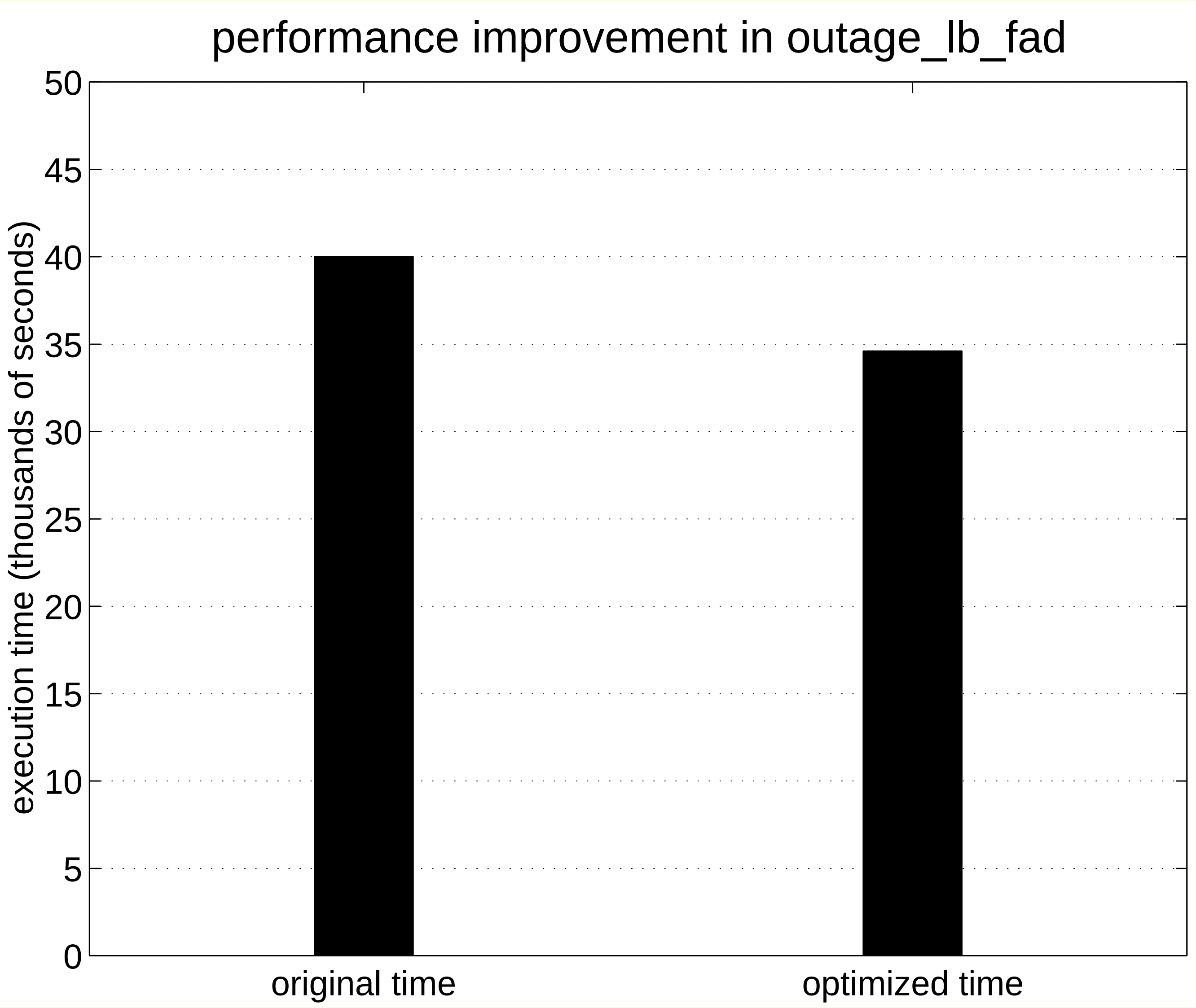
jakes_mp1: vectorization



chan_est: strength reduction



outage_lb_fad: strength reduction



Conclusion

- High pay−off optimizations
  - vectorization
  - common subexpression elimination
  - pre−allocation
  - beating and dragging along
- Two new optimizations
  - procedure strength reduction (10% − 50% gain)
  - procedure vectorization

Related Work

- Source level transformations
  - DeRose’s PhD (UIUC, 1995)
  - Menon & Pingali (Cornell, 1999)
- Currying in functional languages
- Automatic Differentiation
  - ADIFOR project
- APL
  - Abram’s PhD (Stanford, 1970)
- Translation to lower–level languages
  - MCC (Mathworks), MAJIC (UIUC), MATCH (NWU), Menhir (Irisa, France), CONLAB (Univ of Umea, Sweden), Otter (Oregon State Univ)

Current and Future Work

- Implementation
  - Matlab front−end ready
  - Need
    - jump fns, dependence, SSA, array section analysis
    - high−payoff optimizations
    - inter−procedural framework
    - variants database creation and lookup
- Theory
  - Type inferencing
  - Annotation language for library identities