Simple Outer Loop Vectorization == Loop Unroll-and-Jam + SLP

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Simple OLV == Loop Unroll-And-Jam (UnJ) + SLP

- OLV can be visualized as [Nuzman & Zaks, PACT 2008]
  - Unroll the outer loop by k times
  - Jam all the k-inner loop instances of the outer loop
  - Vectorize the loops using SLP
- Ex:

Original

```
for ( i = 0; i < N; i++ ) {
    accum = 0;
    for ( j = 0; j < 5; j++)
         accum += in[j][i] * filter[j];
    out[i] = sqrtf(accum)/particles;
}
```

After Unroll

```
for ( i = 0; i < N; i+= 4 ) {
    accum1 = accum2 =
        accum3 = accum4 = 0;
    for ( j = 0; j < 5; j++)
        accum1 += in[j][i] * filter[j];
    for ( j = 0; j < 5; j++)
        accum2 += in[j][i+1] * filter[j];
    for ( j = 0; j < 5; j++)
        accum3 += in[j][i+2] * filter[j];
    for ( j = 0; j < 5; j++)
        accum4 += in[j][i+3] * filter[j];
    out[i] = sqrtf(accum1)/particles;
    out[i+1] = sqrtf(accum2)/particles;
    out[i+2] = sqrtf(accum3)/particles;
    out[i+3] = sqrtf(accum4)/particles;

}
```

After UnJ

```
for ( i = 0; i < N; i+= 4 ) {
    accum1 = accum2 = … 0;
    for ( j = 0; j < 5; j++) {
         accum1 += in[j][i] * filter[j];
         accum2 += in[j][i+1] * filter[j];
         accum3 += in[j][i+2] * filter[j];
         accum4 += in[j][i+3] * filter[j];
    }
    out[i] = sqrtf(accum1)/particles;
    out[i+1] = sqrtf(accum2)/particles;
    out[i+2] = sqrtf(accum3)/particles;
    out[i+3] = sqrtf(accum4)/particles;

}
```

After SLP

```
<v_particles> = bcast<vparticles>
for ( i = 0; i < N; i+= 4 ) {
    <v_accum> = bcast<0,…,0>;
    for ( j = 0; j < 5; j++) {
         <v_accum> +=
              ld <in[j][i],…,in[j][i+3]> * bcast<filter[j]>;
    }
   st <out[i],…,out[i+3]> =
            vsqrtf(<v_accum>)/<v_particles>;
}
```

Better code generation of inner loop reduction
No gather in the inner loop

Loop Unroll-And-Jam

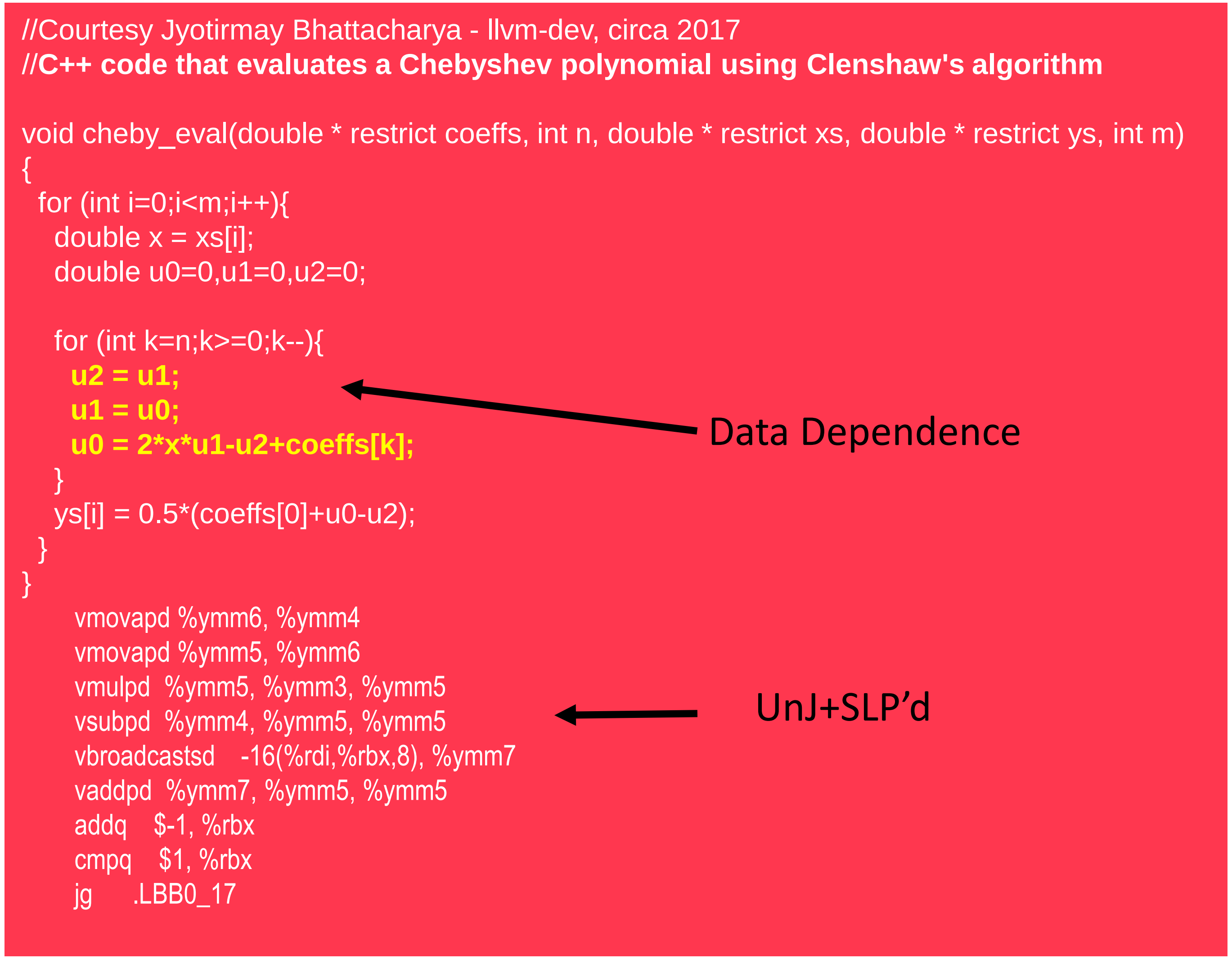
- New Pass introduced in July 2018
  - lib/Transforms/Scalar/LoopUnrollAndJamPass.cpp
- Two flags *–enable-unroll-and-jam* and *–allow-unroll-and-jam*
- Supports pragma *allow_unroll_and_jam(factor)*
- Called ‘after’ SLP in PassManager
  - Scheduling UnJ after SLP is late for our purpose

Modifications in IPO/PassManager to support OLV

- Schedule UnJ Pass before the LoopVectorizer Pass
- Call a bunch of cleanup routines after that
  - Looks like we may need to call LSR as a cleanup pretty early (challenging ?)
  - LSR needed probably because UnJ implementation is not optimal
- … ⇨ UnJ ⇨ *cleanup* ⇨ LV ⇨ … ⇨ SLP ⇨ …
- Need to schedule SLP also before LV ?
  - … ⇨ UnJ ⇨ *cleanup* ⇨ SLP’ ⇨ … ⇨ LV ⇨ … ⇨ SLP’ ⇨ …
  - Else LV may vectorize the jammed inner loop resulting in code which we don’t like ?
  - Very likely that due to costing LV will not vectorize the inner loop
    - Even if it does, we can modify SLP to SLP’ to vectorize “already-vectorized” code

One more example

- Reported in llvm-dev in 2017
  - Inner loop data dependence
  - No outer loop simdization pragma
    - Expects automatic OLV
- UnJ+SLP does OLV
  - Current llvm stage does some OLV but not cleanly
  - mul, sub not vectorized



```
//Courtesy Jyotirmay Bhattacharya - llvm-dev, circa 2017
//C++ code that evaluates a Chebyshev polynomial using Clenshaw's algorithm

void cheby_eval(double * restrict coeffs, int n, double * restrict xs, double * restrict ys, int m)
{
  for (int i=0;i<m;i++){
    double x = xs[i];
    double u0=0,u1=0,u2=0;

    for (int k=n;k>=0;k--){
      u2 = u1;
      u1 = u0;
      u0 = 2*x*u1-u2+coeffs[k];
    }
    ys[i] = 0.5*(coeffs[0]+u0-u2);
  }
}
      vmovapd %ymm6, %ymm4
      vmovapd %ymm5, %ymm6
      vmulpd  %ymm5, %ymm3, %ymm5
      vsubpd  %ymm4, %ymm5, %ymm5
      vbroadcastsd    -16(%rdi,%rbx,8), %ymm7
      vaddpd  %ymm7, %ymm5, %ymm5
      addq    $-1, %rbx
      cmpq    $1, %rbx
      jg      .LBB0_17
```

Data Dependence

UnJ+SLP’d

Open Problems

- Costing and Feasibility
  - Which loops to UnJ
    - Inner loops with reductions
    - Inner Loops with accesses strided on the outer loop index
    - Inner Loops with low trip count
    - Inner loops with data dependence but no dependence on the outer loops
  - What is the unroll factor (UF) ?
    - Assume SLP will work in which case choose UF such that DataSize * UF = SIMD width

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