Code Transformations and Optimizations

Compilers course

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Compilers

OTHER OPTIMIZATIONS

by João M. P. Cardoso

Optimizations

- There are many optimizations
  - Constant Propagation
  - *Strength Reduction*
  - Constant Folding
  - Common Subexpression Elimination
  - Scalar Replacement
  - Elimination of Redundant Memory Accesses: data reuse
  - Dead-Code Elimination
  - Code Movement
  - Data reuse
  - Loop transformations
    - *Loop Unrolling* and…
    - many others

Optimizations

Example (image smooth operation):

```
final public static void doFIR(short[] IN, short[] OUT) {
    int DIM = 350;
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < DIM-3+1; row++) {
      for (int col = 0; col< DIM-3+1; col++) {
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          for (int wcol = 0; wcol<3; wcol++) {
             sumval += IN[(row +wrow)*DIM+(col+wcol)]*K[wrow*3+wcol];
          }
        }
        sumval = sumval / 16;
        OUT[row * DIM + col] =  (short) sumval;
      }
    }
}
```

Optimizations

Constant Propagation

```
final public static void doFIR(short[] IN, short[] OUT) {
    int DIM = 350;
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 350-3+1; row++) {
      for (int col = 0; col< 350-3+1; col++) {
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          for (int wcol = 0; wcol<3; wcol++) {
              sumval  += IN[(row +wrow)*350+(col+wcol)]*K[wrow*3+wcol];
          }
        }
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
      }
    }
}
```

Optimizations

Constant folding (Constant-Expression Evaluation):

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 350-3+1; row++) {     348
      for (int col = 0; col< 350-3+1; col++) {     348
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          for (int wcol = 0; wcol<3; wcol++) {
              sumval  += IN[(row +wrow)*350+(col+wcol)]*K[wrow*3+wcol];
          }
        }
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
      }
    }
}
```

Optimizations

Loop Unrolling:

```
final public static void doFIR(short[] IN, short[] OUT) {

  short[] K =  {1, 2, 1, 2, 4, 2, 1, 2,
  for (int row=0; row < 348; row+
    for (int col = 0; col< 348; col++) {
      int sumval = 0;
      for (int wrow=0; wrow < 3; wrow++) {
        for (int wcol = 0; wcol<3; wcol++) {
           sumval  += IN[(row +wrow)*350+(col+wcol)]*K[wrow*3+wcol];
        }
      }
      sumval = sumval / 16;
      OUT[row * 350 + col] =  (short) sumval;
    }
  }
}
```

```
sumval+= IN[(row +wrow)*350+(col+0)]*K[wrow*3+0];
sumval+= IN[(row +wrow)*350+(col+1)]*K[wrow*3+1];
sumval+= IN[(row +wrow)*350+(col+2)]*K[wrow*3+2];
```

Optimizations

Loop Unrolling:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          sumval+= IN[(row +wrow)*350+(col+0)]*K[wrow*3+0];
          sumval+= IN[(row +wrow)*350+(col+1)]*K[wrow*3+1];
          sumval+= IN[(row +wrow)*350+(col+2)]*K[wrow*3+2];
        }
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
      }
    }
}
```

Optimizations

Algebraic simplification:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          sumval+= IN[(row +wrow)*350+col])*K[wrow*3];
          sumval+= IN[(row +wrow)*350+(col+1)])*K[wrow*3+1];
          sumval+= IN[(row +wrow)*350+(col+2)])*K[wrow*3+2];
        }
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
      }
    }
}
```

Optimizações

Loop Unrolling:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval = 0;
        for (int wrow=0; wrow < 3; wrow++) {
          sumval+= IN[(row +wrow)*350+col])*K[wrow*3];
          sumval+= IN[(row +wrow)*350+(col+1)])*K[wrow*3+1];
          sumval+= IN[(row +wrow)*350+(col+2)])*K[wrow*3+2];
        }
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
      }
    }
}
```

Optimizations

Loop Unrolling:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval = 0;
        sumval+= IN[(row +0)*350+col]*K[0*3];
        sumval+= IN[(row +0)*350+(col+1)]*K[0*3+1];
        sumval+= IN[(row +0)*350+(col+2)]*K[0*3+2];
        sumval+= IN[(row +1)*350+col]*K[1*3];
        sumval+= IN[(row +1)*350+(col+1)]*K[1*3+1];
        sumval+= IN[(row +1)*350+(col+2)]*K[1*3+2];
        sumval+= IN[(row +2)*350+col]*K[2*3];
        sumval+= IN[(row +2)*350+(col+1)]*K[2*3+1];
        sumval+= IN[(row +2)*350+(col+2)]*K[2*3+2];
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval; }}}
```

Optimizations

Algebraic simplifications+ *constant folding*:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval= IN[row*350+col]*K[0];
         sumval+=   IN[row*350+(col+1)]*K[1];
         sumval+=   IN[row*350+(col+2)]*K[2];
         sumval+=   IN[(row +1)*350+col]*K[3];
         sumval+=   IN[(row +1)*350+(col+1)]*K[4];
         sumval+=   IN[(row +1)*350+(col+2)]*K[5];
         sumval+=   IN[(row +2)*350+col]*K[6];
         sumval+=   IN[(row +2)*350+(col+1)]*K[7];
         sumval+=   IN[(row +2)*350+(col+2)]*K[8];
         sumval = sumval / 16;
         OUT[row * 350 + col] =  (short) sumval;
}}}
```

Optimizations

Scalar Replacement:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
     for (int row=0; row < 348; row++) {
       for (int col = 0; col< 348; col++) {
         int sumval= IN[row*350+col];
         sumval+=   IN[row*350+col+1]*2;
         sumval+=   IN[row*350+col+2];
         sumval+=   IN[(row +1)*350+col]*2;
         sumval+=   IN[(row +1)*350+col+1]*4;
         sumval+=   IN[(row +1)*350+col+2]*2;
         sumval+=   IN[(row +2)*350+col];
         sumval+=   IN[(row +2)*350+col+1]*2;
         sumval+=   IN[(row +2)*350+col+2];
         sumval = sumval / 16;
         OUT[row * 350 + col] =  (short) sumval;
     }}}
```

Optimizations

Code Elimination of declarations and initializations not used:

```
final public static void doFIR(short[] IN, short[] OUT) {
    short[] K =  {1, 2, 1, 2, 4, 2, 1, 2, 1};
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval= IN[row*350+col];
        sumval+=    IN[row*350+col+1]*2;
        sumval+=    IN[row*350+col+2];
        sumval+=    IN[(row +1)*350+col]*2;
        sumval+=    IN[(row +1)*350+col+1]*4;
        sumval+=    IN[(row +1)*350+col+2]*2;
        sumval+=    IN[(row +2)*350+col];
        sumval+=    IN[(row +2)*350+col+1]*2;
        sumval+=    IN[(row +2)*350+col+2];
        sumval = sumval / 16;
        OUT[row * 350 + col] =  (short) sumval;
    }}}
```

Optimizations

Code Elimination of declarations and initializations not used:

```
final public static void doFIR(short[] IN, short[] OUT) {

  for (int row=0; row < 348; row++) {
    for (int col = 0; col< 348; col++) {
      int sumval= IN[row*350+col];
      sumval+=   IN[row*350+col+1]*2;
      sumval+=   IN[row*350+col+2];
      sumval+=   IN[(row +1)*350+col]*2;
      sumval+=   IN[(row +1)*350+col+1]*4;
      sumval+=   IN[(row +1)*350+col+2]*2;
      sumval+=   IN[(row +2)*350+col];
      sumval+=   IN[(row +2)*350+col+1]*2;
      sumval+=   IN[(row +2)*350+col+2];
      sumval = sumval / 16;
      OUT[row * 350 + col] =  (short) sumval;
  }}}
```

Optimizations

Strength reduction:

```
final public static void doFIR(short[] IN, short[] OUT) {

    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval= IN[row*350+col];
        sumval+=   IN[row*350+col+1]<<1;
        sumval+=   IN[row*350+col+2];
        sumval+=   IN[(row +1)*350+col]<<1;
        sumval+=   IN[(row +1)*350+col+1]<<2;
        sumval+=   IN[(row +1)*350+col+2]<<1;
        sumval+=   IN[(row +2)*350+col];
        sumval+=   IN[(row +2)*350+col+1]<<1;
        sumval+=   IN[(row +2)*350+col+2];
        sumval = sumval >> 4;
        OUT[row * 350 + col] =  (short) sumval;
    }}}
```

Optimizations

After algebraic optimizations and reassociation:

```
final public static void doFIR(short[] IN, short[] OUT) {
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int sumval=IN[row*350+col];
        sumval+=IN[row*350+col+1]<<1;
        sumval+=IN[row*350+col+2];
        sumval+=IN[350*row +350+col]<<1;
        sumval+=IN[350*row +351+col]<<2;
        sumval+=IN[350*row +352+col]<<1;
        sumval+=IN[350*row +700+col];
        sumval+=IN[350*row +701+col]<<1;
        sumval+=IN[350*row +702+col];
        sumval = sumval >> 4;
        OUT[row * 350 + col] =  (short) sumval;
     }}}
```

Optimizations

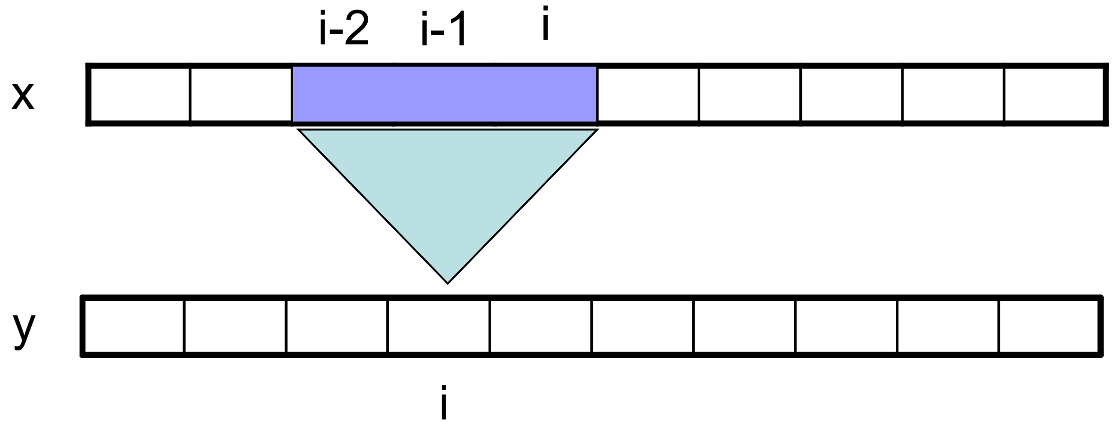
Common subexpression elimination:

```
final public static void doFIR(short[] IN, short[] OUT) {
    for (int row=0; row < 348; row++) {
      for (int col = 0; col< 348; col++) {
        int row_350_col = row*350 + col;
        int sumval= IN[row_350_col];
        sumval+=    IN[row_350_col + 1]<<1;
        sumval+=    IN[row_350_col + 2];
        sumval+=    IN[row_350_col + 350]<<1;
        sumval+=    IN[row_350_col + 351]<<2;
        sumval+=    IN[row_350_col + 352]<<1;
        sumval+=    IN[row_350_col + 700];
        sumval+=    IN[row_350_col + 701]<<1;
        sumval+=    IN[row_350_col + 702];
        sumval = sumval >> 4;
        OUT[row_350_col] =  (short) sumval;
    }}}
```

Optimizations

Data reuse:

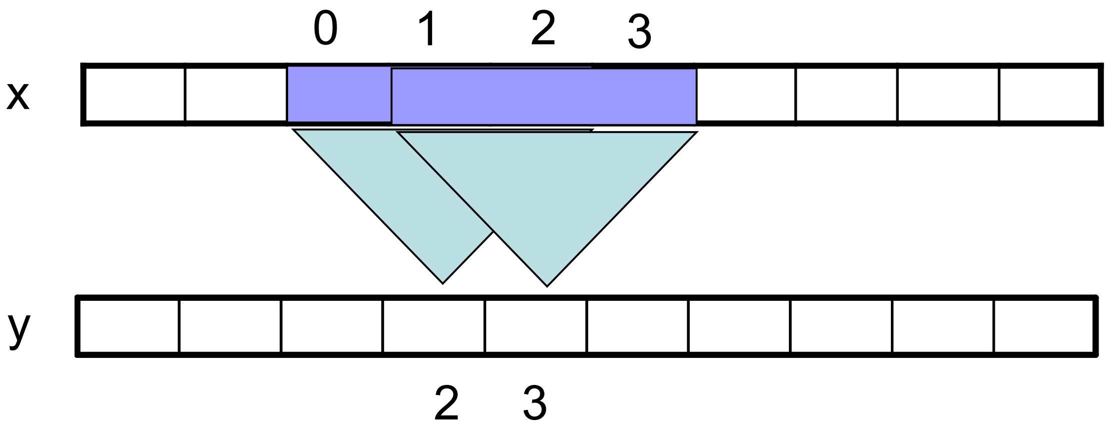
```
for (int i = 2; i< N; i++) {
   y[i] = x[i] + x[i-1] + x[i-2];
}
```



Optimizations

Data reuse:

```
for (int i = 2; i< N; i++) {
   y[i] = x[i] + x[i-1] + x[i-2];
}
```

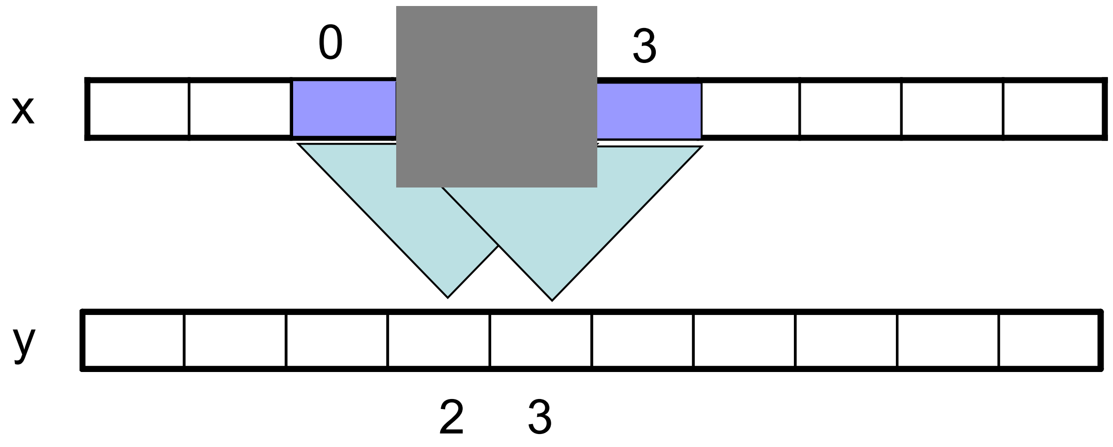


Optimizations

Data reuse:

```
for (int i = 2; i< N; i++) {
   y[i] = x[i] + x[i-1] + x[i-2];
}
```

```
int x_2 = x[0]
int x_1 = x[1];
Int x_0;
for (int i = 2; i< N; i++) {
   x_0 = x[i];
   y[i] = x_0 + x_1 + x_2;
   x_2 = x_1;
   x_1 = x_0;
}
```



Summary

- There are many optimizations and their impact depends on the code and on the target machine
- Usually, programmers use existent compiler flags that represent a set of optimizations (e.g., gcc’s -O2 and –O3)
- An important step is the selection of the optimizations to apply according to the code (e.g., of a function), target machine, and goal (e.g., performance, energy consumption)