Recap from last class

- Real-time scheduling
  - Ensuring that all tasks can meet their deadlines
  - Responsiveness > throughput
    - Worst-case performance
- Schedulability
  - Schedulable utilization bound
- Optimal scheduling algorithms
  - RMS vs. EDF
- Priority inversion
- End-to-end scheduling framework
  - Dependency constraints among subtasks
  - Multi-processor scheduling

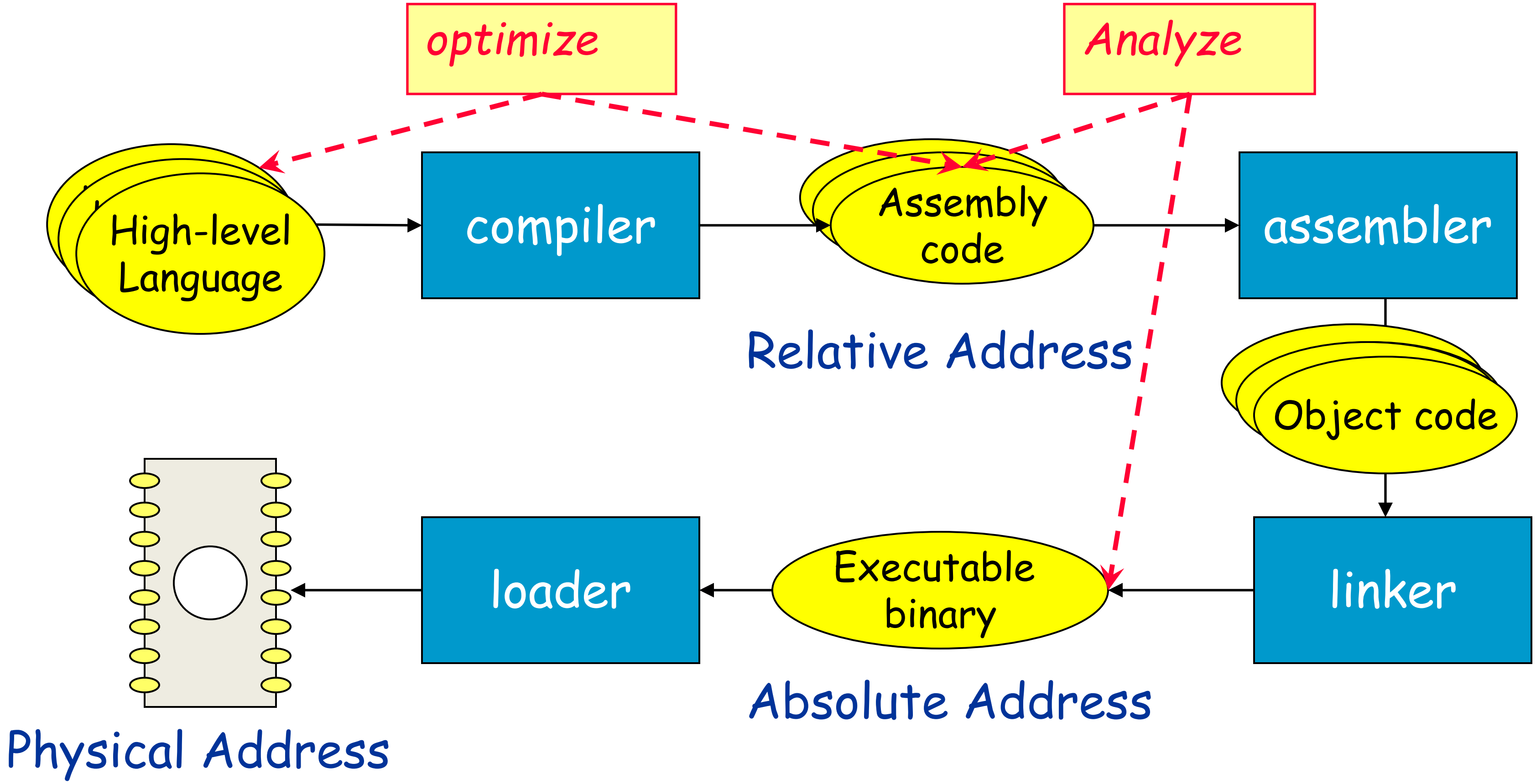
ECE 1175
Embedded Systems Design

Program Optimization I

Wei Gao

Program Transformation

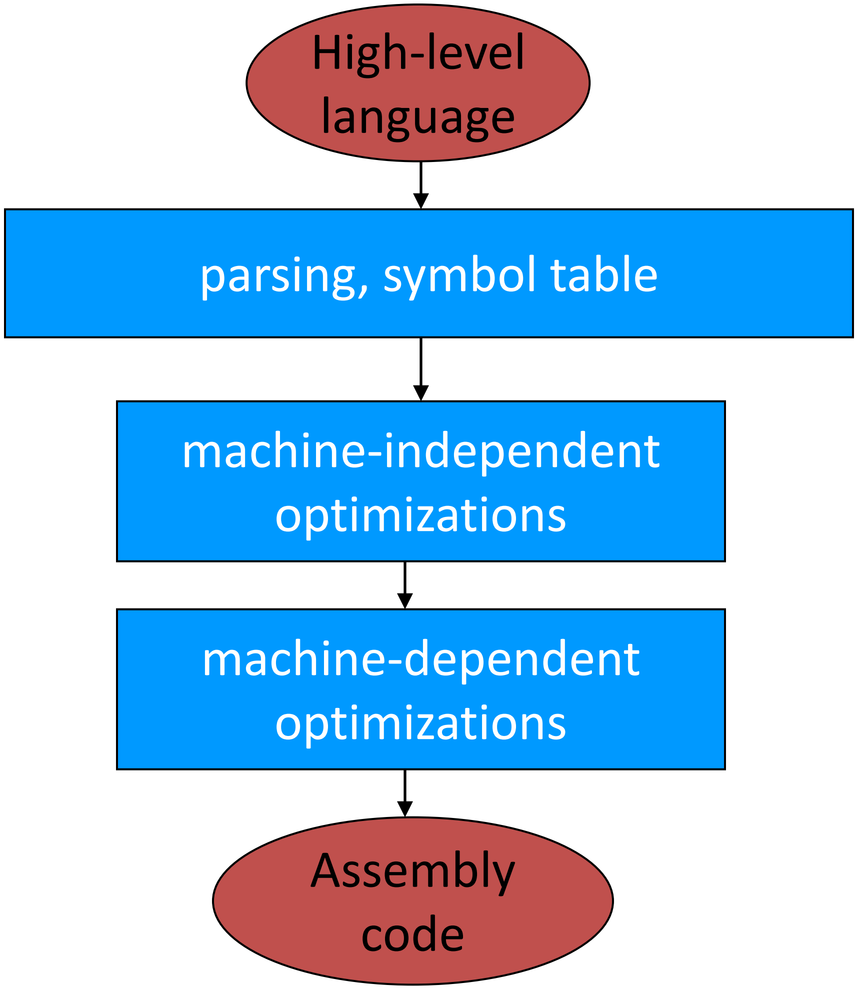
- How high-level program is transformed to executable binary code?



Compilation

- Compilation strategy (by Wirth):
  - compilation = translation + optimization
- Compiler determines quality of code:
  - use of CPU resources;
  - memory access scheduling;
  - code size.

Basic compilation phases



Basic Compilation Optimization

- 1. Expression simplification
- 2. Dead code elimination
- 3. Function inlining
- 4. Loop optimizations
- 5. Register allocation

1. Expression Simplification

- Algebraic:
  - `a*b + a*c` ⇨ `a*(b+c)`
  - Three operations change to two operations
- Constant folding:
  - `for (i=0; i<8+1; i++)`

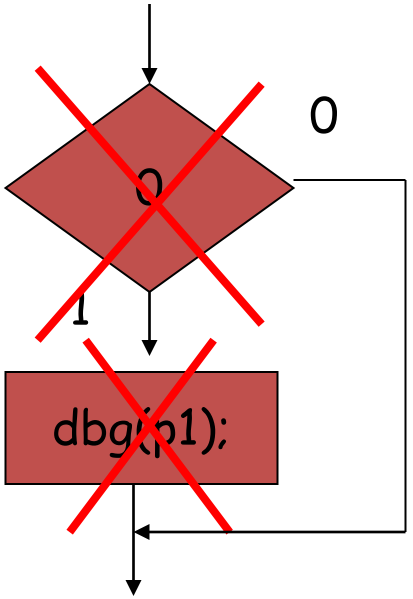
  ⇨ `for (i=0; i<9; i++)`
- Strength reduction of constant multiplication
  - `a*2`⇨`a<<1; a*3`⇨`a*(2+1)`⇨`a<<1+a;`
  - `a*1000`⇨`a*(1024-16-8)`⇨`a<<10 – a<<4 – a<<3`
  - SHIFT, ADD, SUB take one cycle but multiplication takes about 10 cycles

2. Dead Code Elimination

- Dead code:

```
#define DEBUG 0
if (DEBUG) dbg(p1);
```

- Can be eliminated by analysis of control flow, constant folding



3. Function inlining

```
int foo(a,b,c) { return a + b - c;}
z = foo(w,x,y);
⇨
z = w + x - y;
```

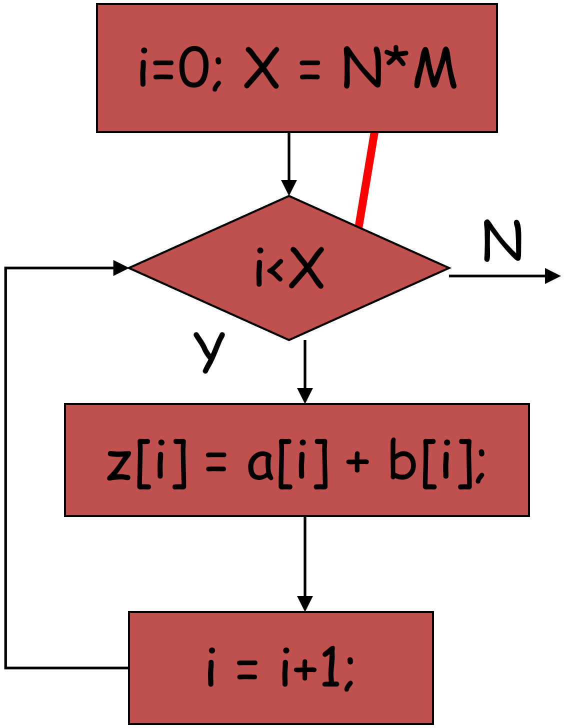
- An inline function's body is inserted directly (like a substitution) in the compiled code at the point where the function is called.
- Improve performance by reducing function call overhead

4. Loop Optimizations

- Loops are good targets for optimization.
- Basic loop optimizations:
  - Code motion;
  - Reduce loop overhead;
  - Increase opportunities for pipelining and parallelism;

Code Motion

```
for (i=0; i<N*M; i++)
  z[i] = a[i] + b[i];
```

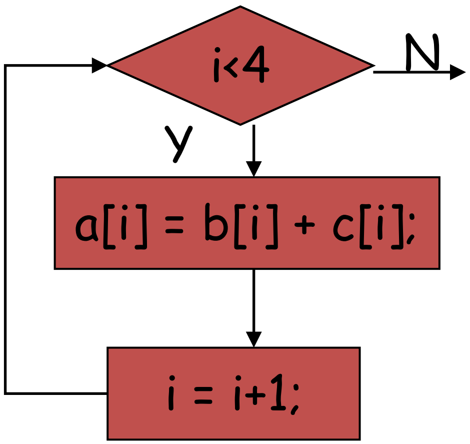


- Move computation inside a loop to the outside to avoid doing it repeatedly.

Loop Unrolling

- Reduces loop overhead

```
for (i=0; i<4; i++)
  a[i] = b[i] * c[i];
⇨
for (i=0; i<4; i+=2) {
  a[i] = b[i] * c[i];
  a[i+1] = b[i+1] * c[i+1];
}
```



- May allow to be executed in CPU’s pipeline
- May increase the code size

Loop Fusion

- Combines multiple loops into one loop to reduce loop overhead

```
for (i=0; i<N; i++) a[i] = b[i] * 5;
for (j=0; j<N; j++) w[j] = c[j] * d[j];
```

⇨

```
for (i=0; i<N; i++) {
  a[i] = b[i] * 5; w[i] = c[i] * d[i];
}
```

- Necessary conditions:
  - Loops share the same index
  - No dependencies between two loops

5. Register Allocation

- Processor registers
  - A very small amount of very fast computer memory
  - Used to speed the execution of computer programs
  - Provides quick access to most commonly used values
  - Memory hierarchy: register – cache – main memory – disk
- Reduce the number of used registers
  - Fit more frequently used variables in registers
  - Load once, use many times

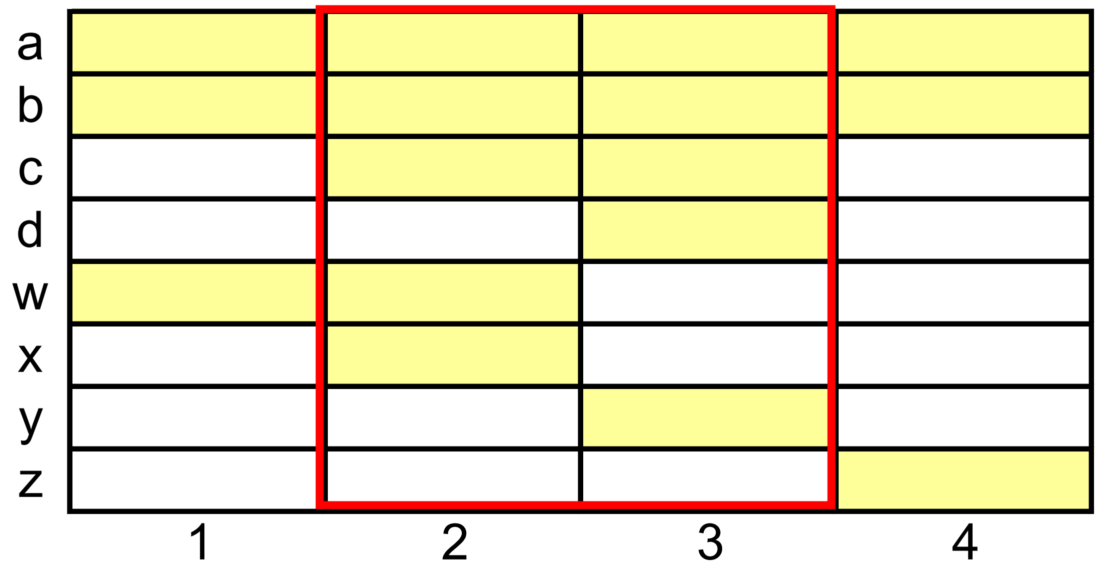
→ Reduce number of cache/memory access

→ Reduce energy consumption

Register Lifetime Graph

no. of needed registers = 5

```
1. w = a + b;
2. x = c + w;
3. y = c + d;
4. z = a - b;
```

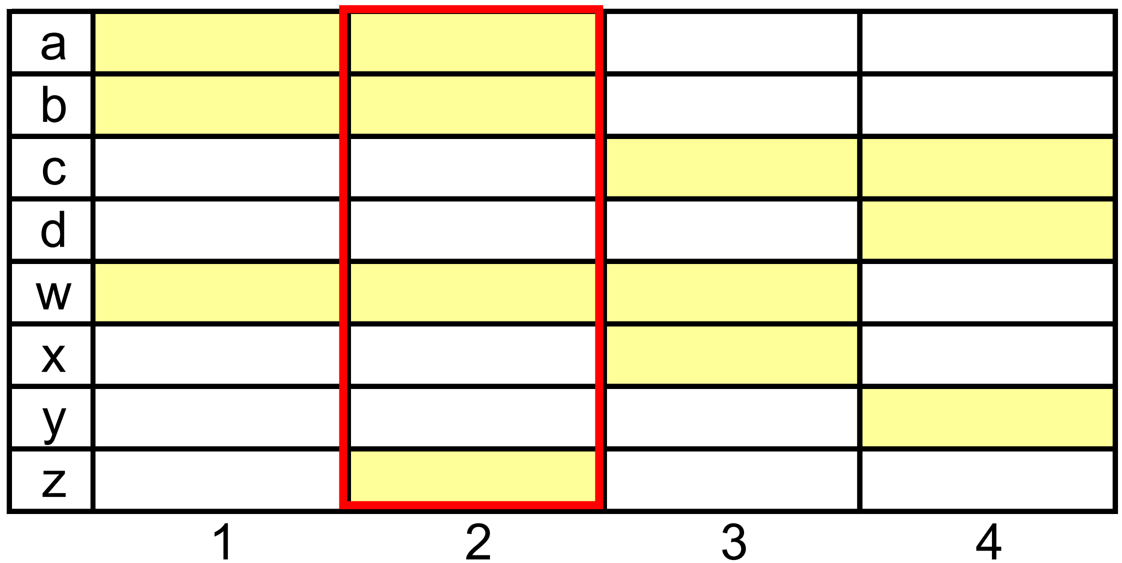


means this variable should be loaded to register

After Rescheduling

no. of needed registers = 4

```
1. w = a + b;
2. z = a - b;
3. x = c + w;
4. y = c + d;
```



Cannot change dependencies between instructions!

Summary of Compilation Optimization

- Use registers efficiently.
- Optimize loops.
- Optimize function calls.
- Optimize cache behavior:
  - instruction conflicts can be handled by rewriting code, rescheduling;