Embedded Program Design

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Components for Embedded Programs

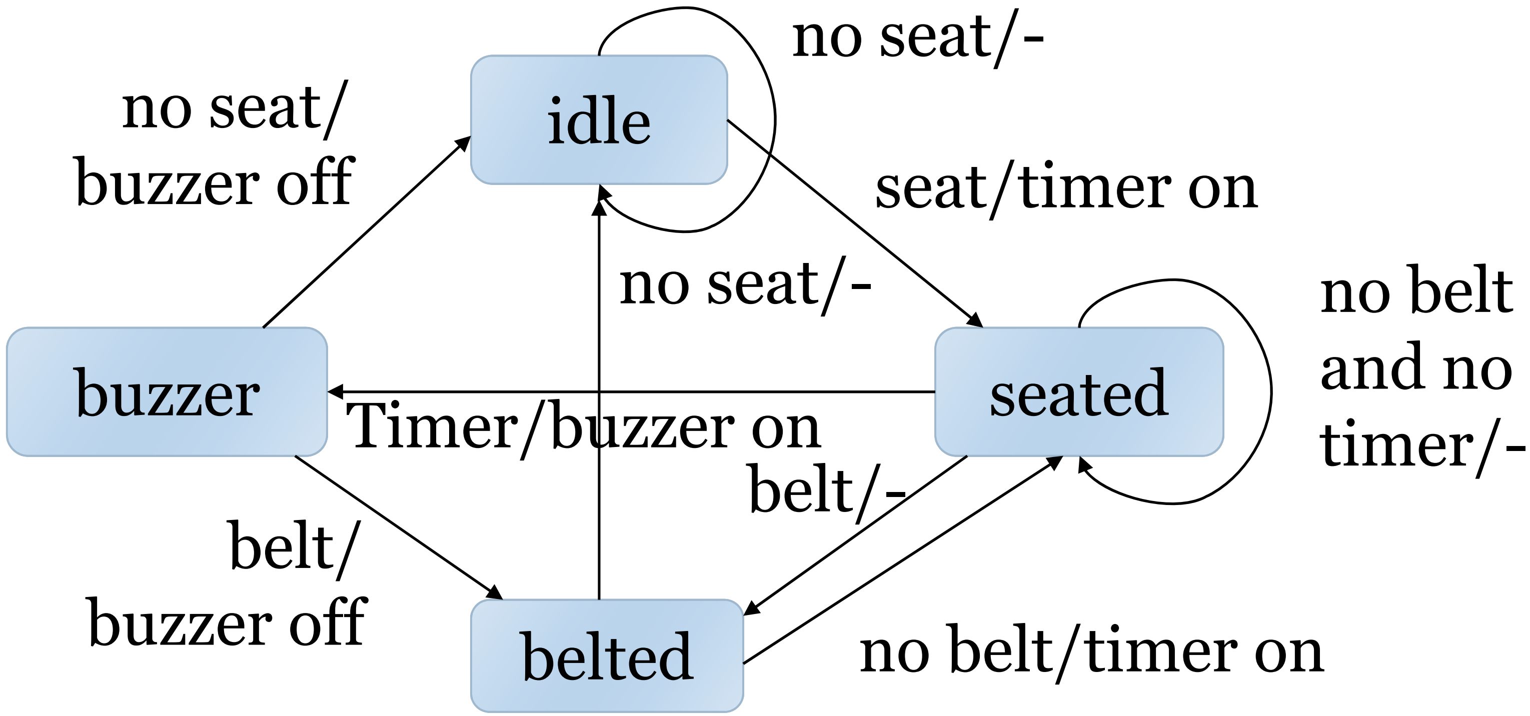
State Machines

- State machine keeps internal state as a variable, changes state based on inputs.

- Uses:
  - Control-dominated code
  - Reactive systems (e.g., user interfaces)

State Machine Example

- Inputs/outputs (- : no action)

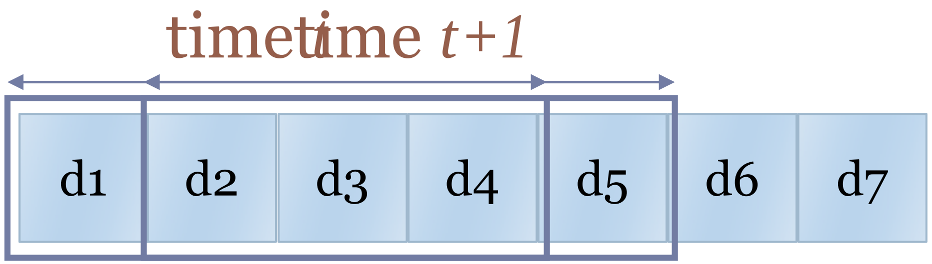


C Implementation

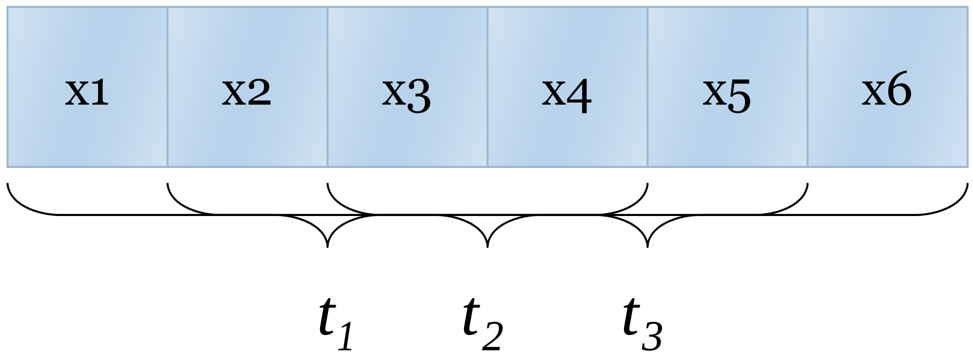
```c
#define    IDLE      0
#define    SEATED    1
#define    BELTED    2
#define    BUZZER    3

switch (state)  {
    case IDLE:        if (seat) state = SEATED;
                      break;
    case SEATED:      if (belt) state = BELTED;
                      else if (timer) state = BUZZER;
                      break;
    case BELTED:      if (!seat) state = IDLE;
                      else if (!belt) state = SEATED;
                      break;
    case BUZZER:      if (belt) state = BELTED;
                      else if (!seat) state = IDLE;
                      break;
}
```

Circular Buffers (1)

- Commonly used in signal processing
  - New data constantly arrives
  - Each data has a limited lifetime
- Use a circular buffer to hold the data stream



Circular Buffers (2)

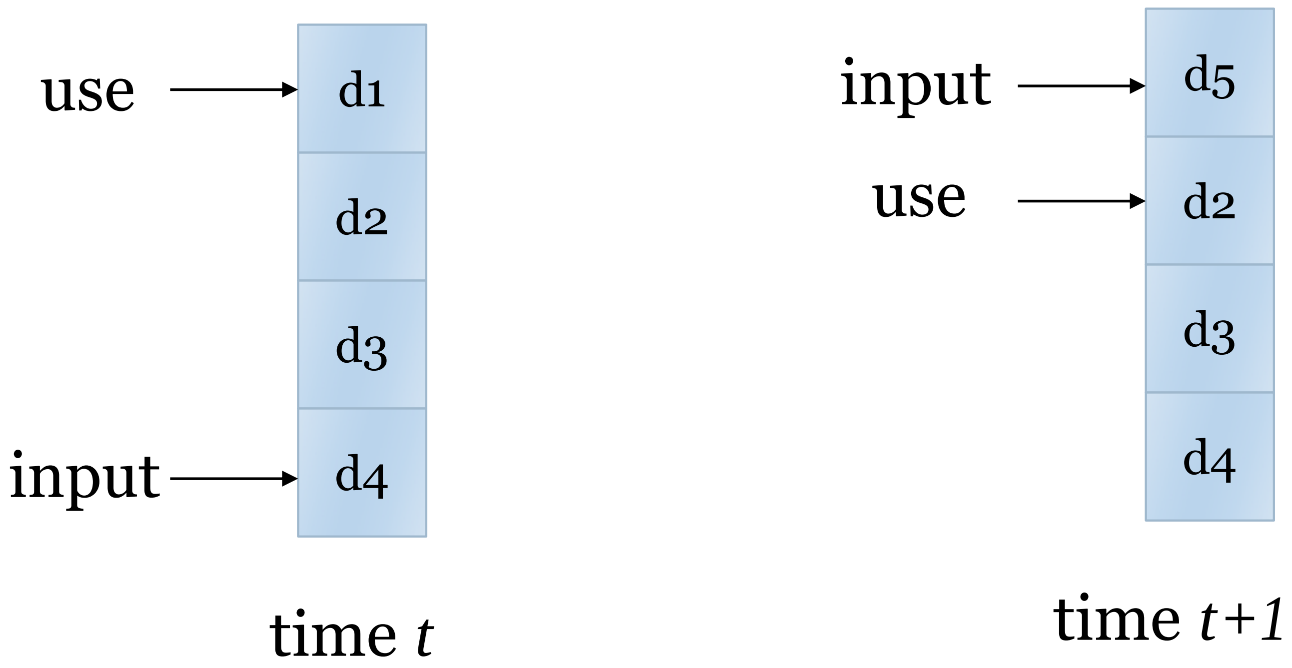


Data stream

Circular buffer

Circular Buffers (3)

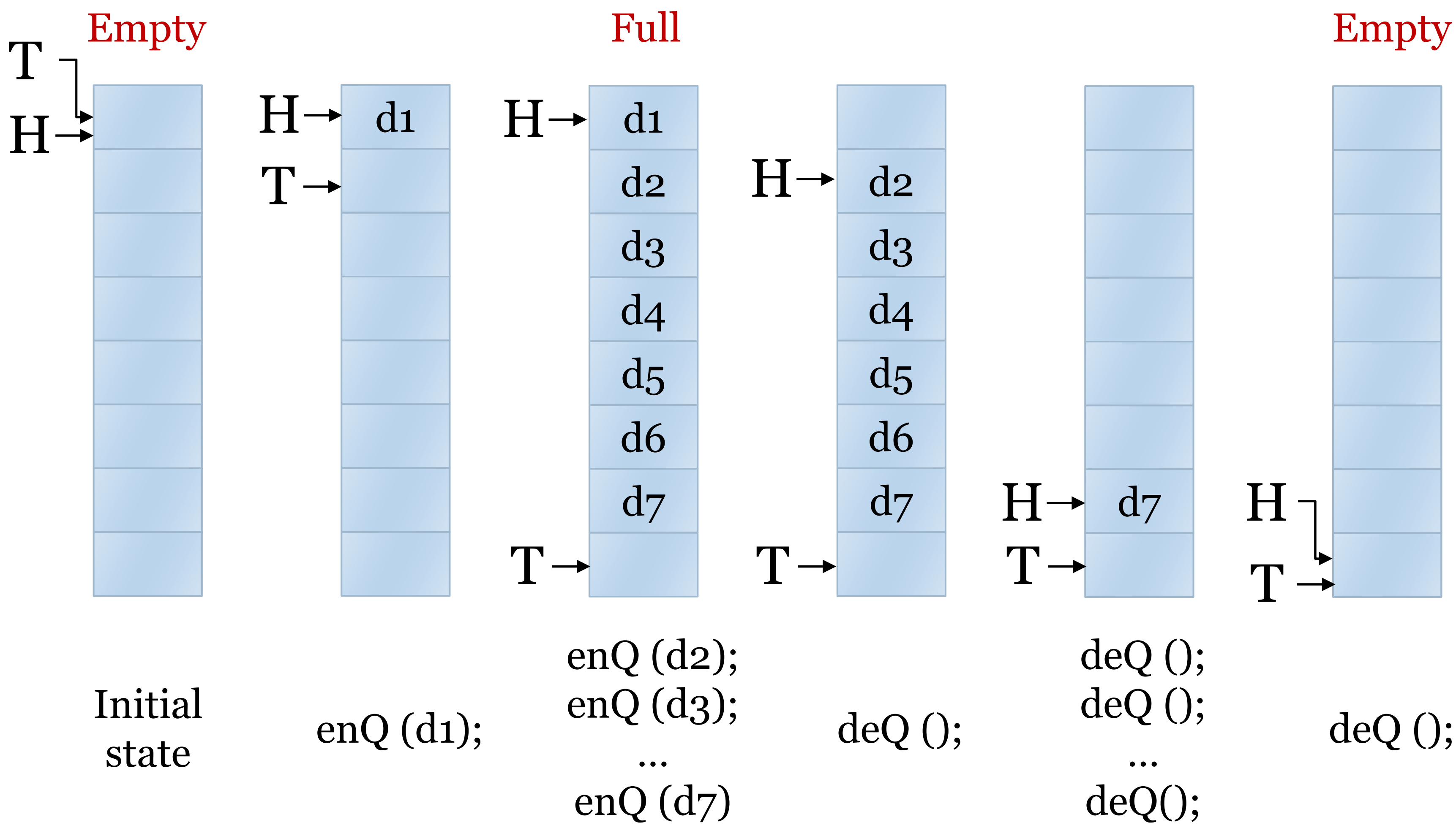
- Indexes locate currently used data, current input data:



Queues

- Elastic buffer: holds data that arrives irregularly
- Used in signal processing and event processing
- Implementation with a linked list
  - Queue can grow to an arbitrary size
  - Requires dynamic memory allocation

Buffer-based Queues



C Implementation

```
#define    Q_SIZE    32
#define    Q_MAX     (Q_SIZE – 1)

int q[Q_SIZE];
int head, tail;

void initqueue ()  {
    head = 0;
    tail = 0;
}

int wrap (int i)  {
    return ((i+1) % Q_SIZE);
}
```

```
void enqueue (int val)  {
    if (wrap (tail) == head)
        error (QUEUE_FULL);
    q[tail] = val;
    tail = wrap (tail);
}

int dequeue ()  {
    int retval;
    if (head == tail)
        error (QUEUE_EMPTY);
    retval = q[head];
    head = wrap (head);
    return retval;
}
```

Control/Data Flow Graph

Models of Programs

- Source code is not a good representation for programs:
  - Clumsy
  - Leaves much information implicit
- Compilers derive intermediate representations to manipulate and optimize the program

Data Flow Graph (DFG)

- Does not represent control
- Models basic block: code with no entry or exit
- Describes the minimal ordering requirements on operations
- Represented in single-assignment form

Single Assignment Form

```
x = a + b;
y = c – d ;
z = x * y;
y = b + d;
```

original basic block

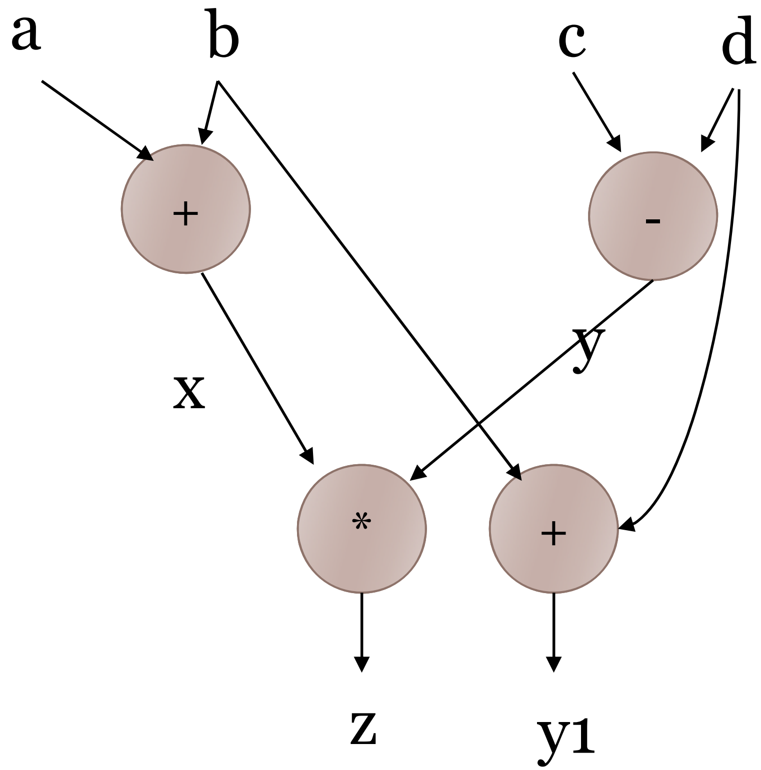
```
x = a + b;
y = c – d ;
z = x * y;
y1 = b + d;
```

single assignment form

DFGs and Partial Orders

- The DFG defines a partial ordering of the operations in the basic block.

```
x = a + b;
y = c – d ;
z = x * y;
y1 = b + d;
```



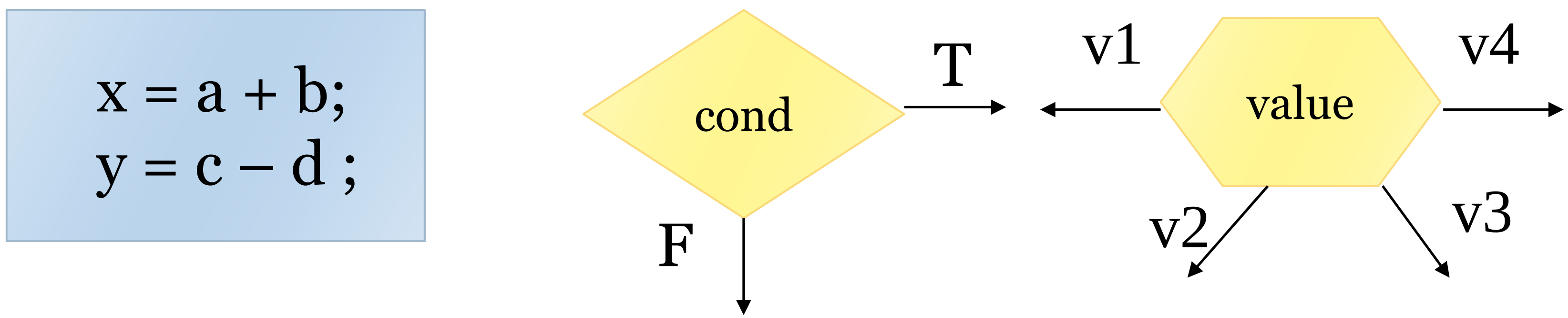
DFG

Control/Data Flow Graph

- CDFG: represents control and data
- Users data flow graphs as components
- Two types of nodes:

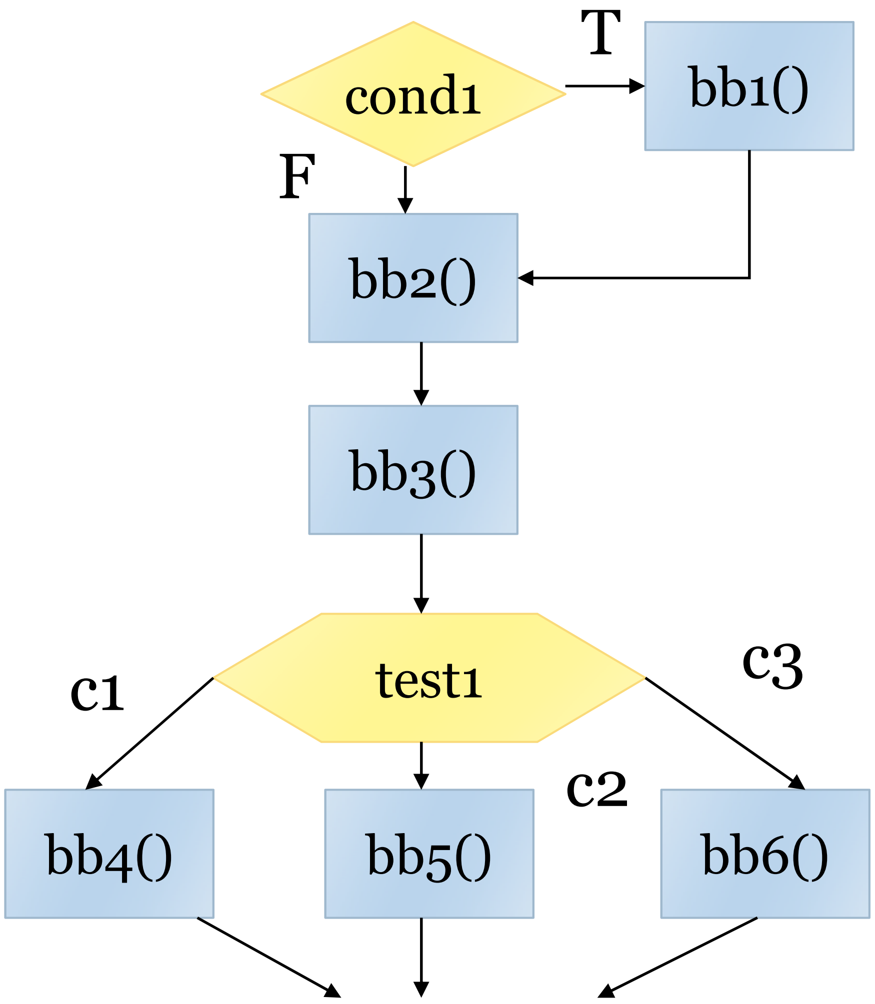
Data flow nodes

Decision nodes



CDFG Example

```
if (cond1) bb1();
else bb2();
bb3();
switch (test1)  {
    case c1: bb4(); break;
    case c2: bb5(); break;
    case c3: bb6(); break;
}
```



For Loop

```
for (i = 0; i < N; i++)
    loop_body();
```

```
i = 0;
while (i < N)  {
    loop_body ();
    i++;
}
```