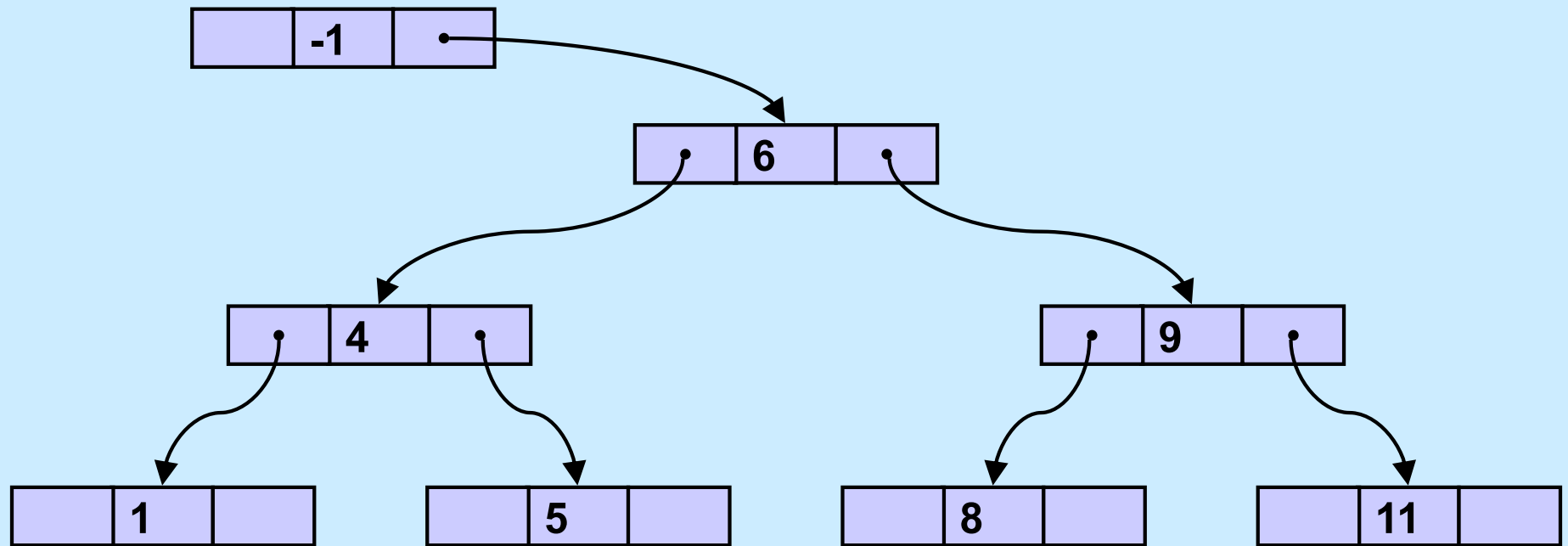


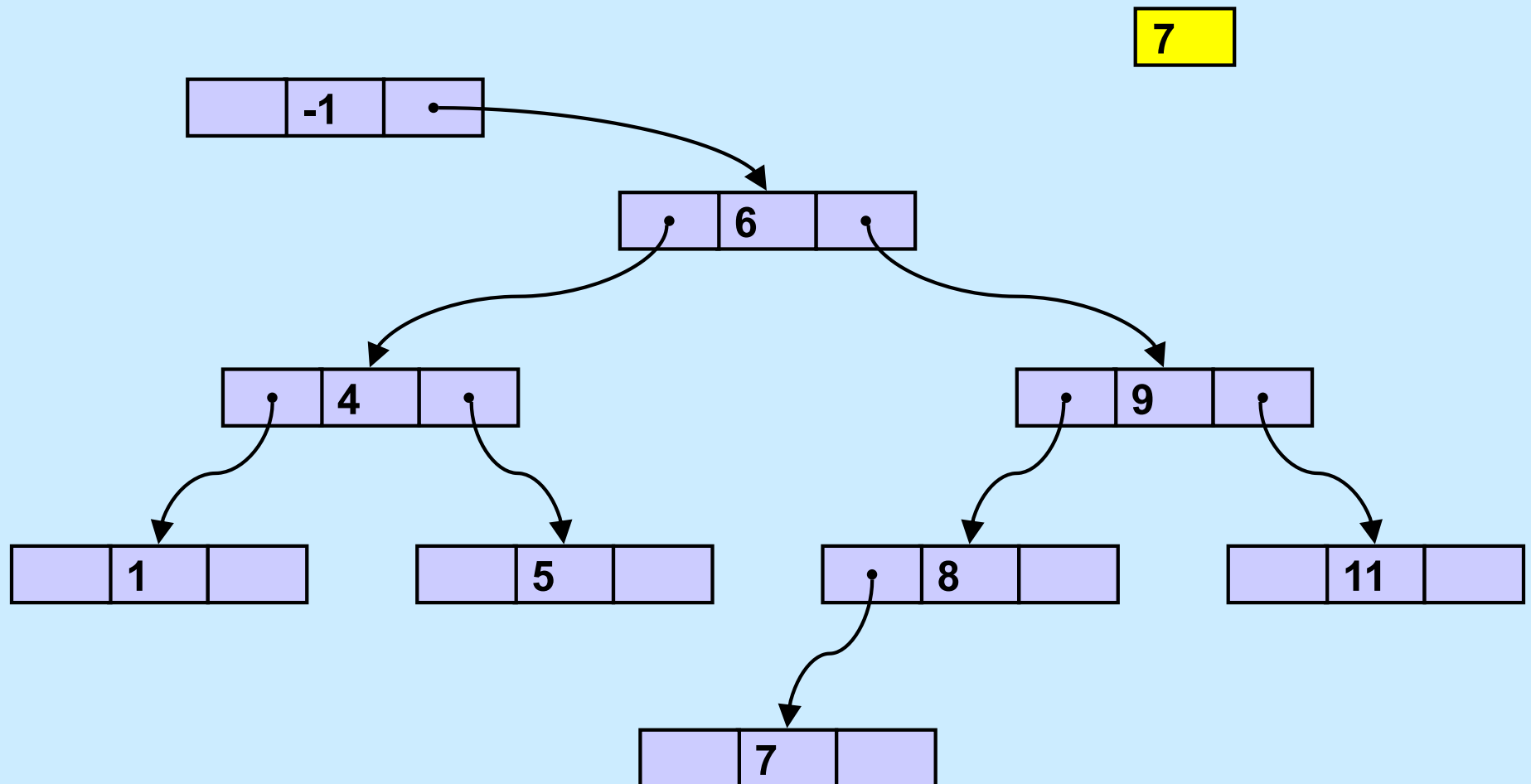
CS 33

Multithreaded Programming IV

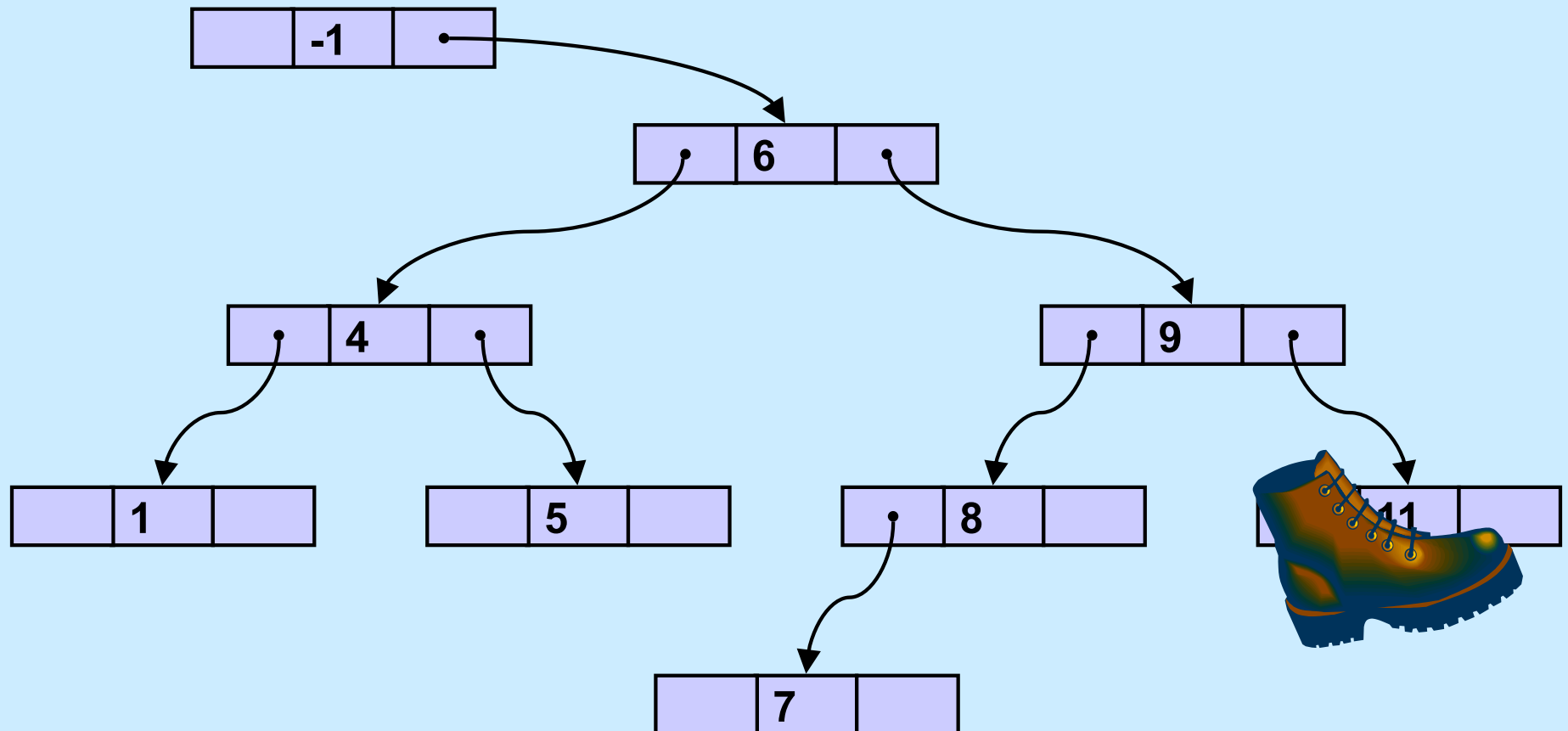
Binary Search Tree



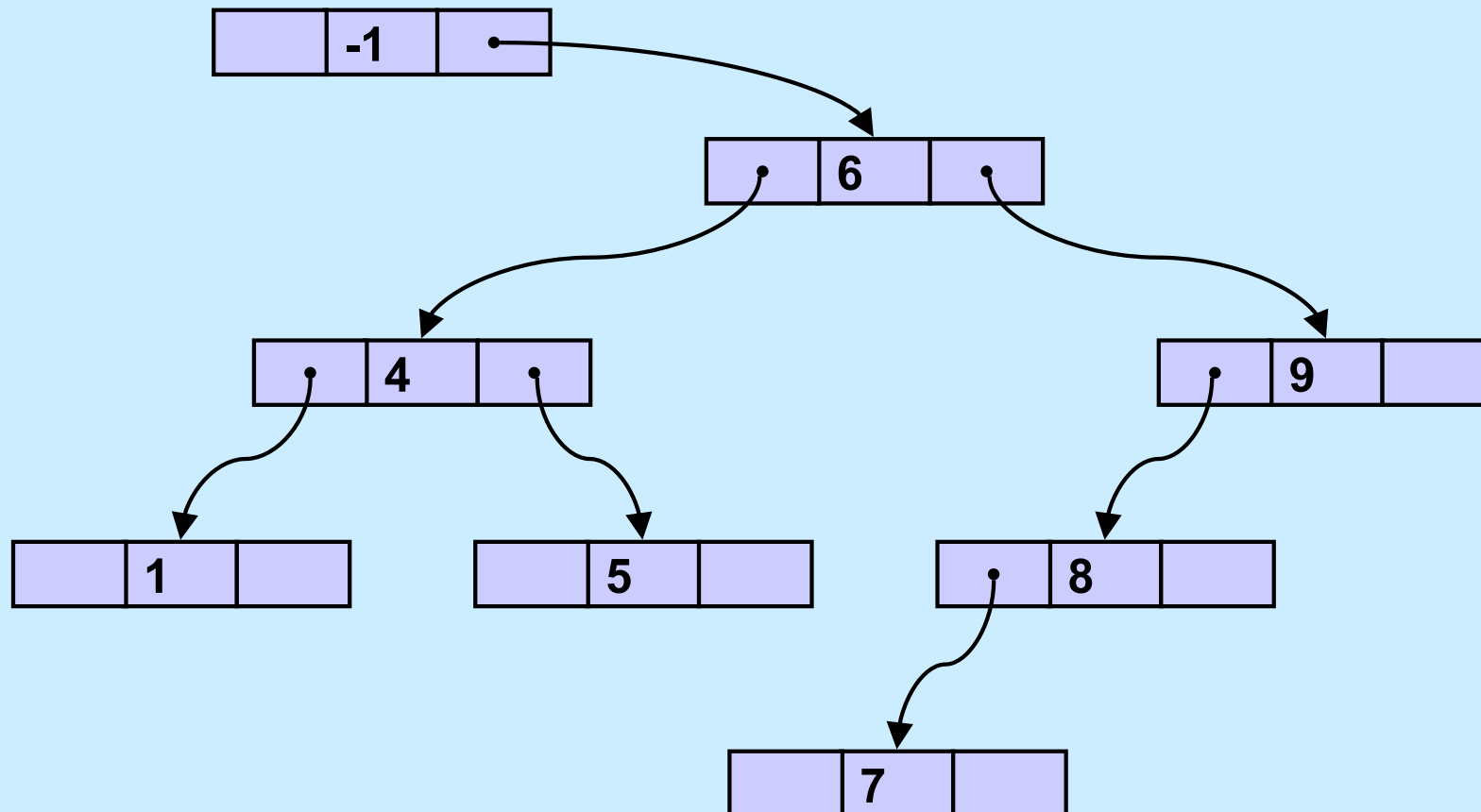
Binary Search Tree: Insertion



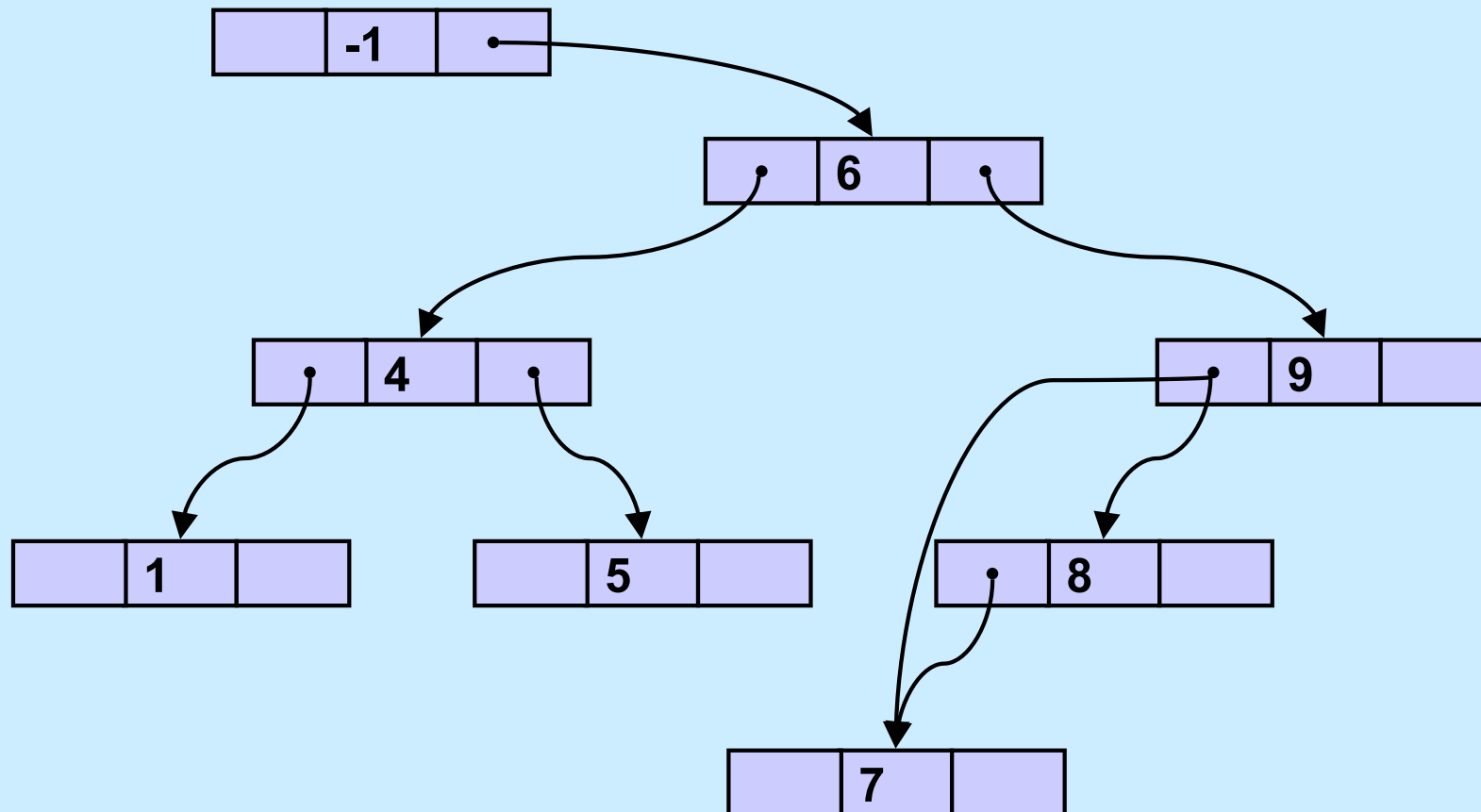
Binary Search Tree: Deletion of Leaf



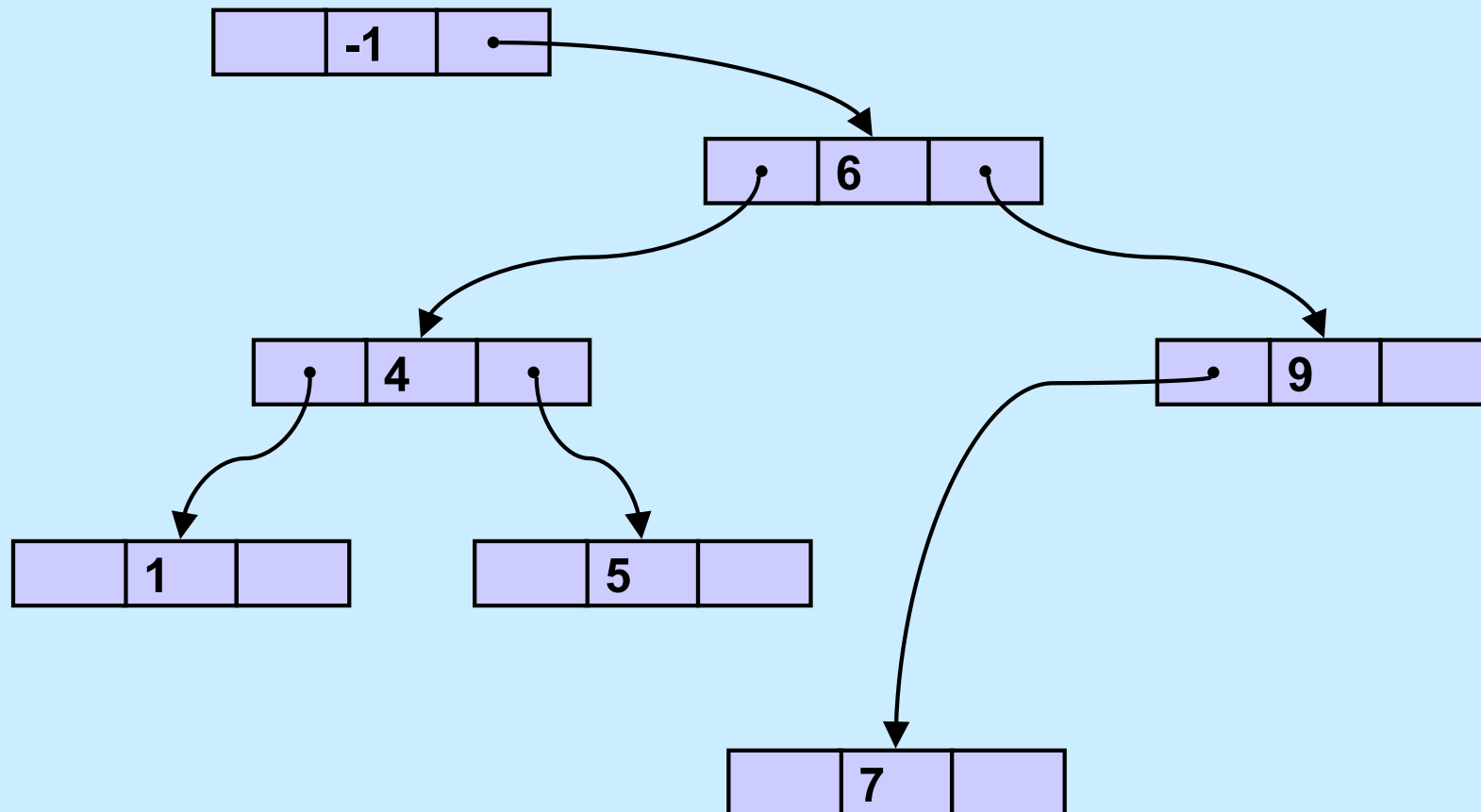
Binary Search Tree: Deletion of Leaf



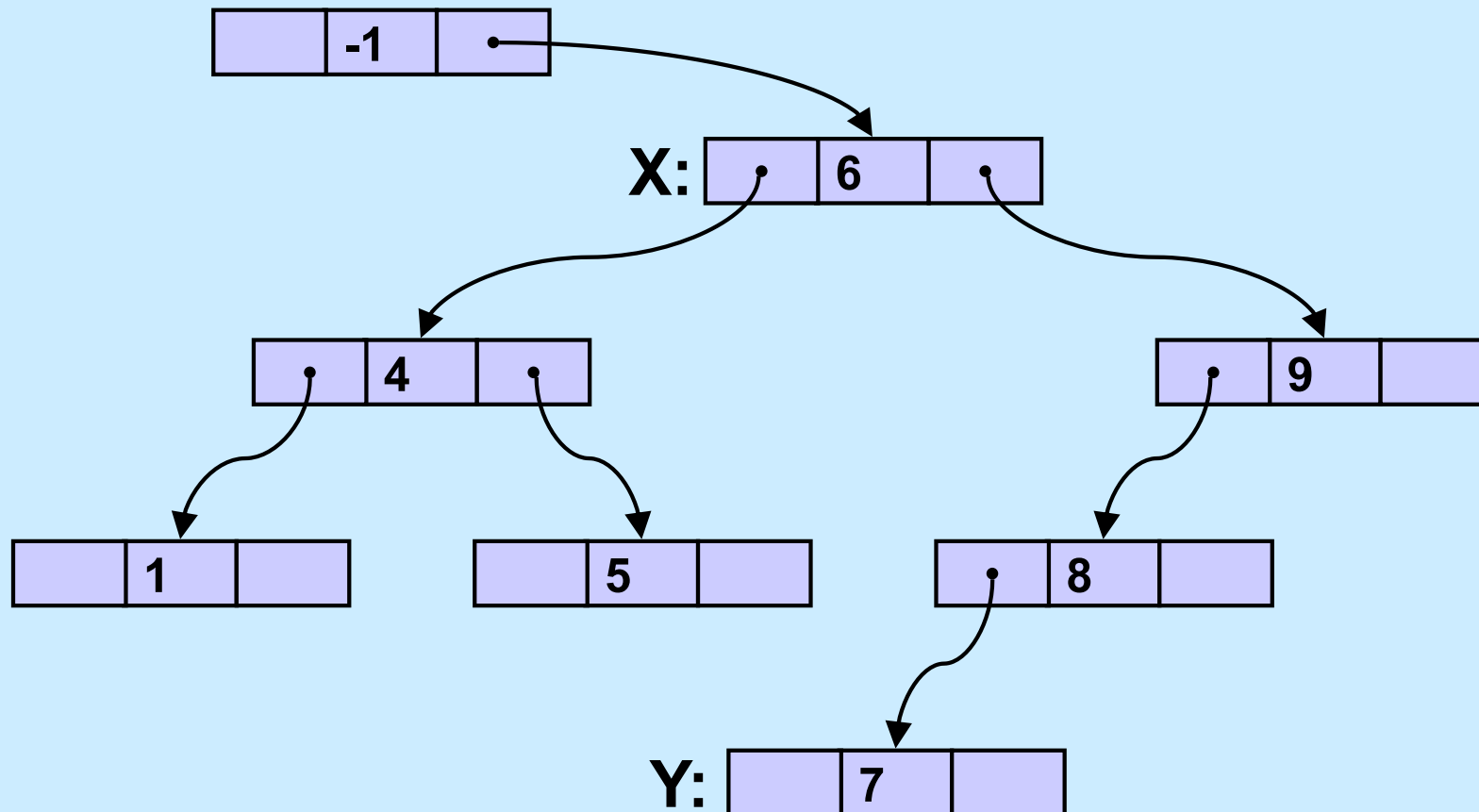
Binary Search Tree: Deletion of Node with One Child



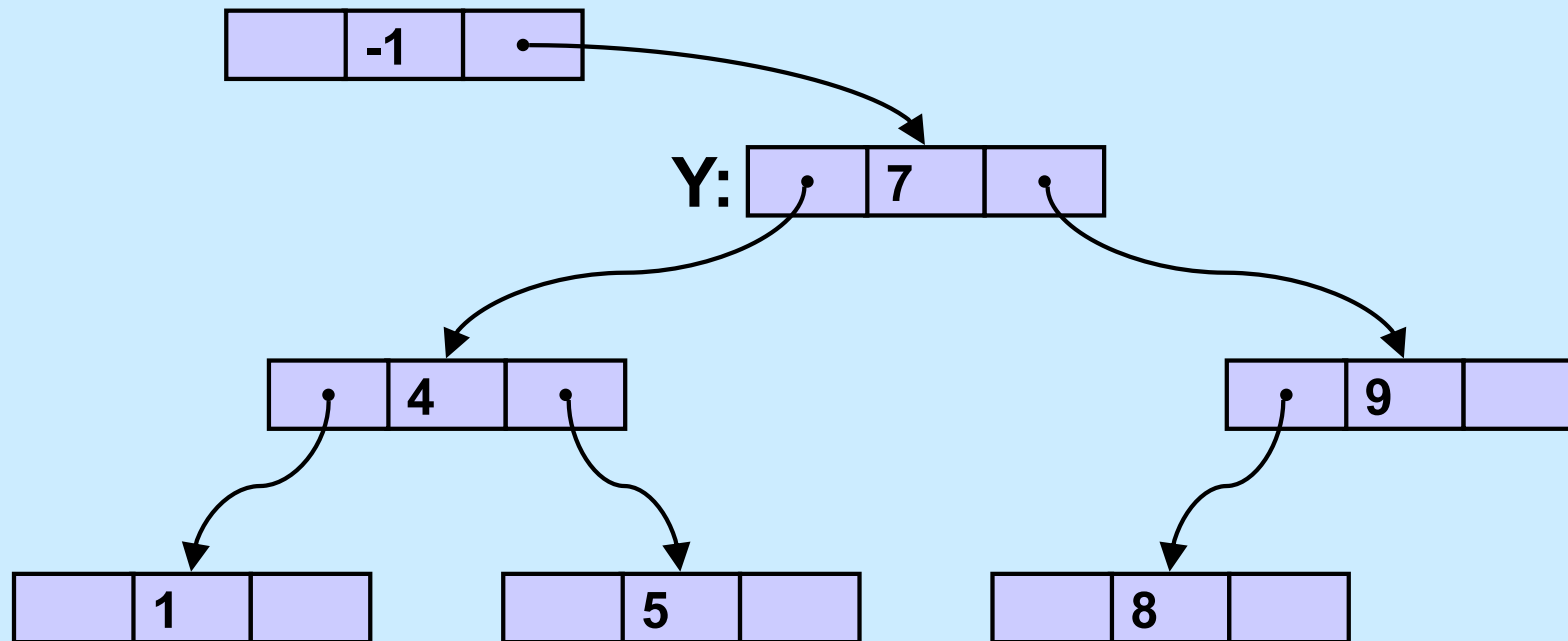
Binary Search Tree: Deletion of Node with One Child



Binary Search Tree: Deletion of Node with Two Children



Binary Search Tree: Deletion of Node with Two Children



C Code: Search

```
Node *search(int key,
             Node *parent, Node **parentp) {
    Node *next;
    Node *result;
    if (key < parent->key) {
        if ((next = parent->lchild)
            == 0) {
            result = 0;
        } else {
            if (key == next->key) {
                result = next;
            } else {
                result = search(key,
                               next, parentpp);
                return result;
            }
        }
    } else {
        if ((next = parent->rchild)
            == 0) {
            result = 0;
        } else {
            if (key == next->key) {
                result = next;
            } else {
                result = search(key,
                               next, parentpp);
                return result;
            }
        }
    }
    if (parentpp != 0)
        *parentpp = parent;
    return result;
}
```

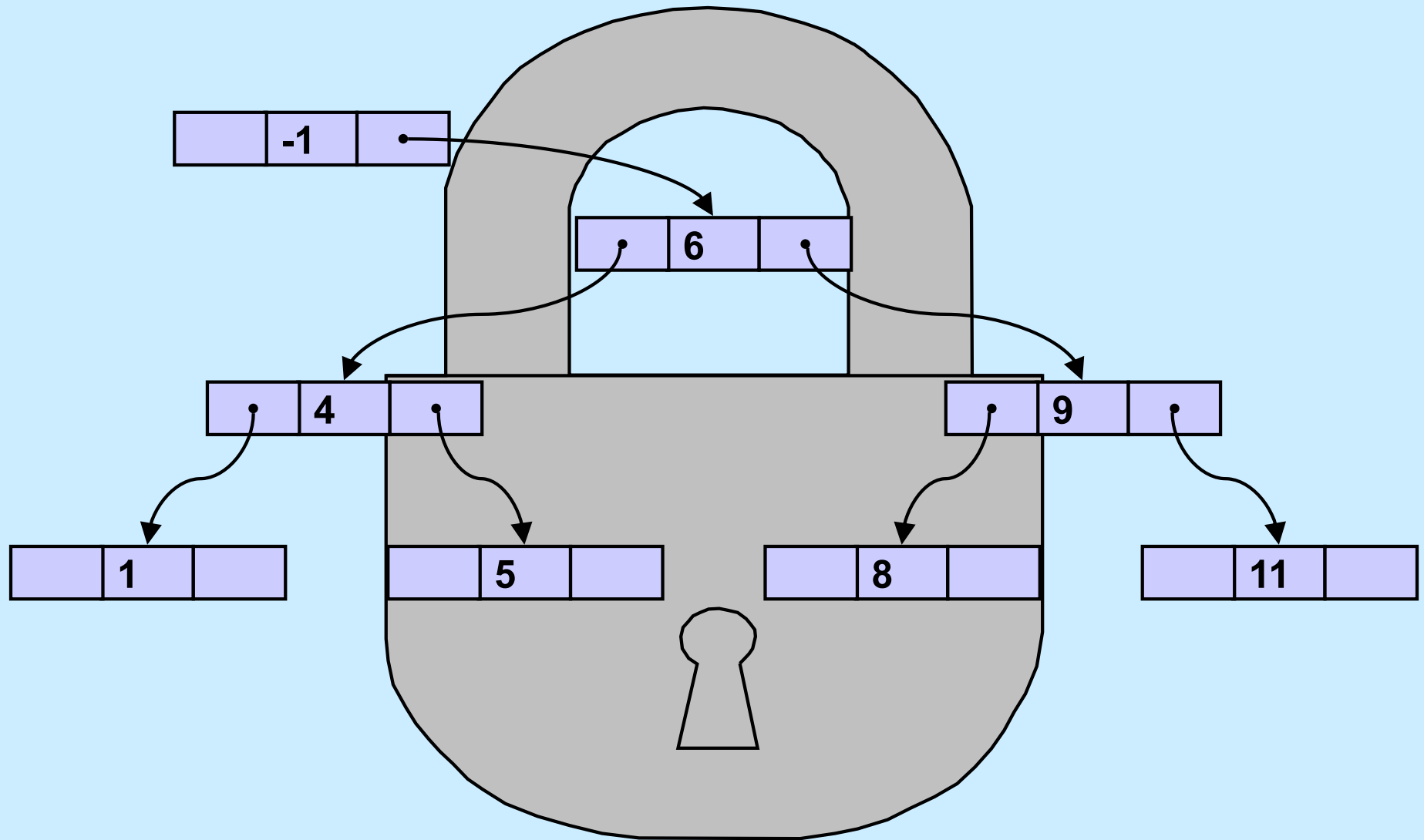
C Code: Add

```
int add(int key) {
    Node *parent, *target, *newnode;
    if ((target = search(key, &head, &parent)) != 0) {
        return 0;
    }
    newnode = malloc(sizeof(Node));
    newnode->key = key;
    newnode->lchild = newnode->rchild = 0;
    if (name < parent->name)
        parent->lchild = newnode;
    else
        parent->rchild = newnode;
    return 1;
}
```

Readers-Writers API

```
int pthread_rwlock_init(pthread_rwlock_t *lock,  
    pthread_rwlockattr_t *att);  
int pthread_rwlock_destroy(pthread_rwlock_t *lock);  
int pthread_rwlock_rdlock(pthread_rwlock_t *lock);  
int pthread_rwlock_wrlock(pthread_rwlock_t *lock);  
int pthread_rwlock_tryrdlock(pthread_rwlock_t *lock);  
int pthread_rwlock_trywrlock(pthread_rwlock_t *lock);  
int pthread_timedrwlock_rdlock(pthread_rwlock_t *lock,  
    struct timespec *ts);  
int pthread_timedrwlock_wrlock(pthread_rwlock_t *lock,  
    struct timespec *ts);  
int pthread_rwlock_unlock(pthread_rwlock_t *lock);
```

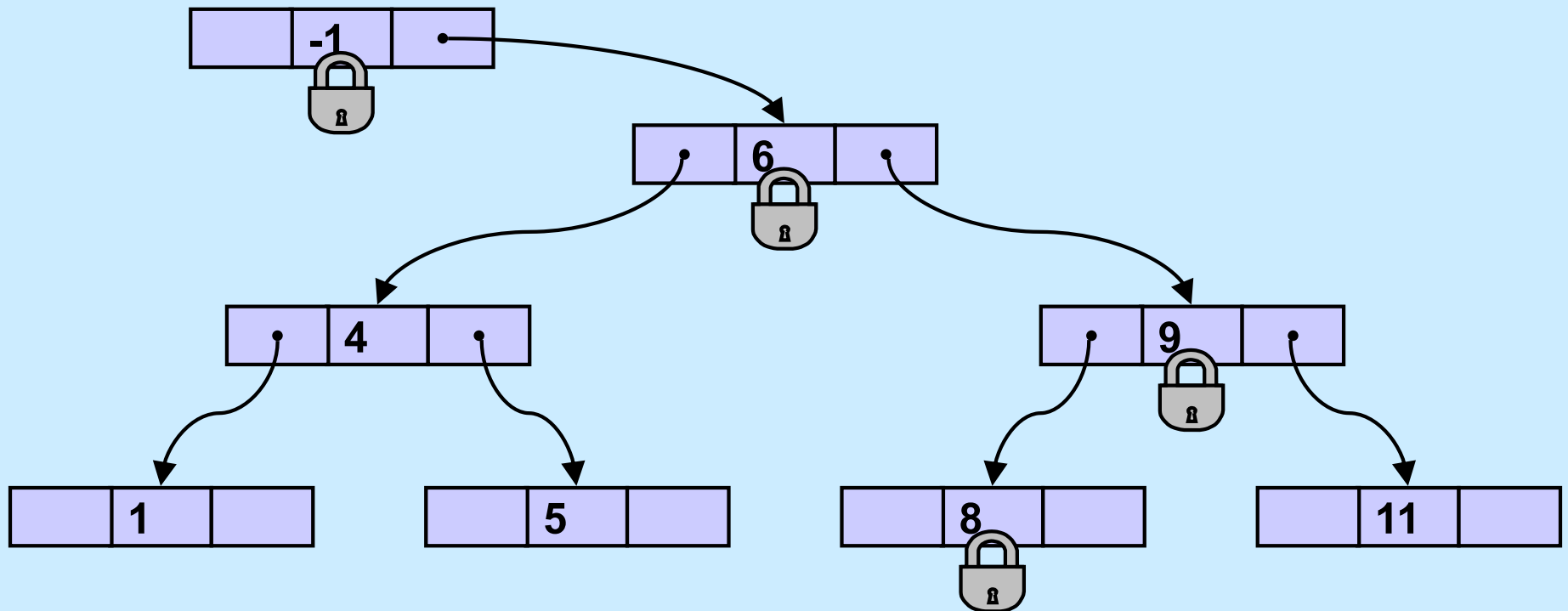
Binary Search Tree with Coarse-Grained Synchronization



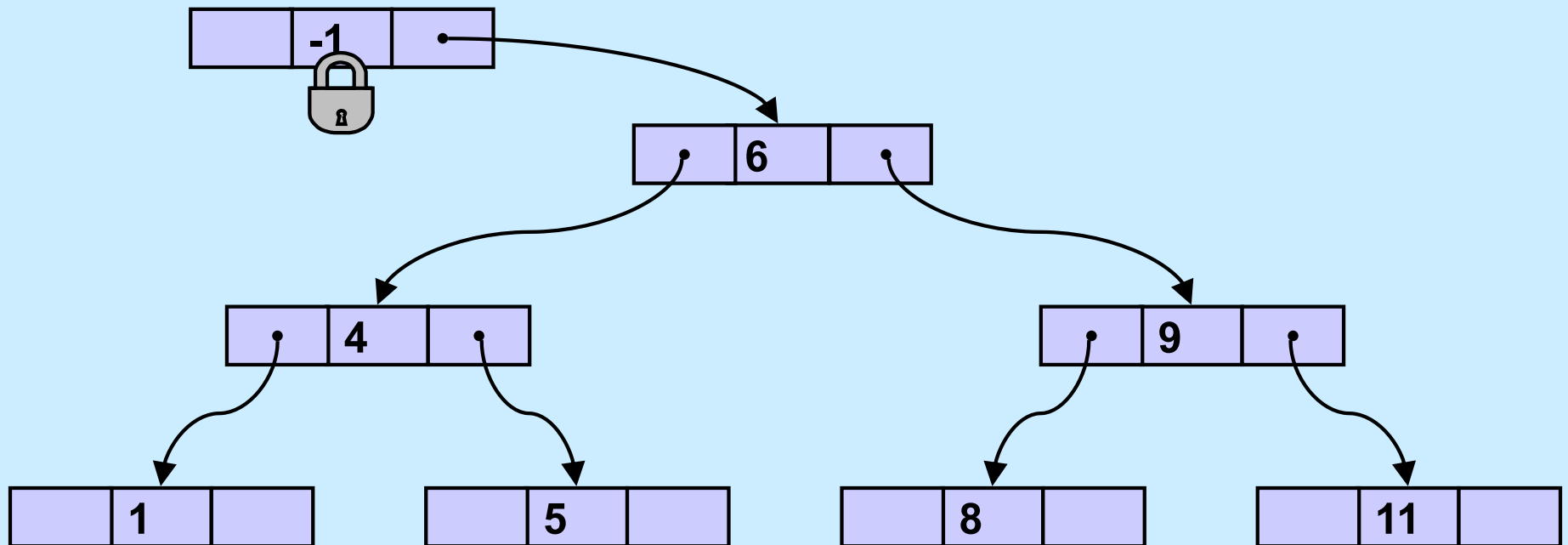
C Code: Add with Coarse-Grained Synchronization

```
int add(int key) {
    Node *parent, *target, *newnode;
    pthread_rwlock_wrlock(&tree_lock);
    if ((target = search(key, &head, &parent)) != 0) {
        pthread_rwlock_unlock(&tree_lock);
        return 0;
    }
    newnode = malloc(sizeof(Node));
    newnode->key = key;
    newnode->lchild = newnode->rchild = 0;
    if (name < parent->name)
        parent->lchild = newnode;
    else
        parent->rchild = newnode;
    pthread_rwlock_unlock(&tree_lock);
    return 1;
}
```

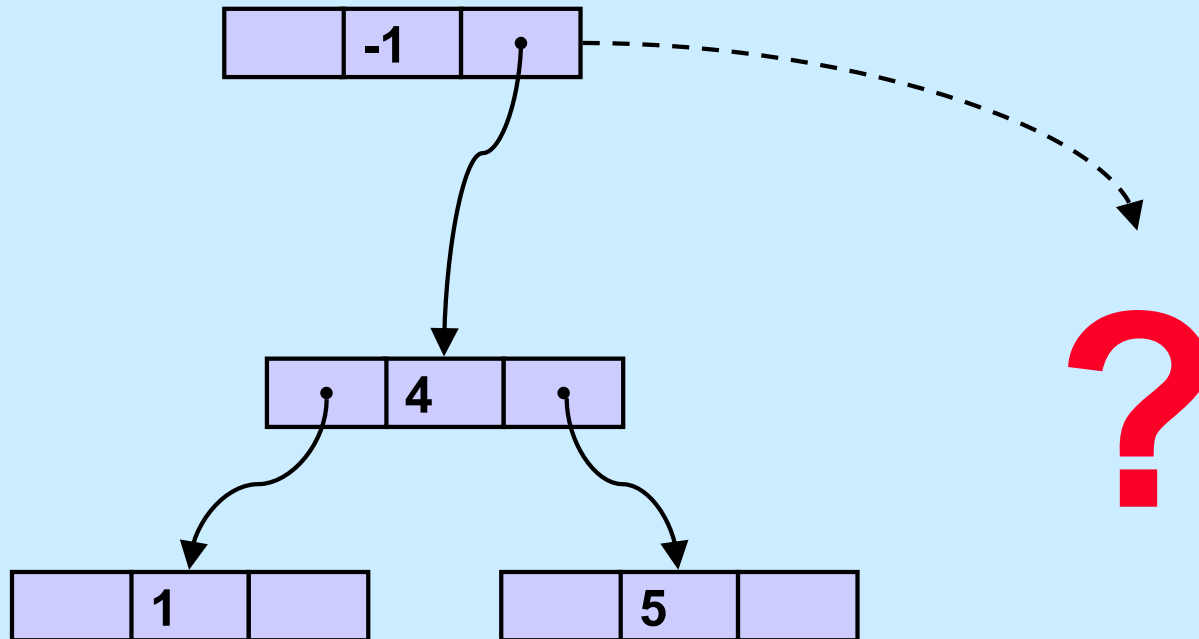
Binary Search Tree with Fine-Grained Synchronization I



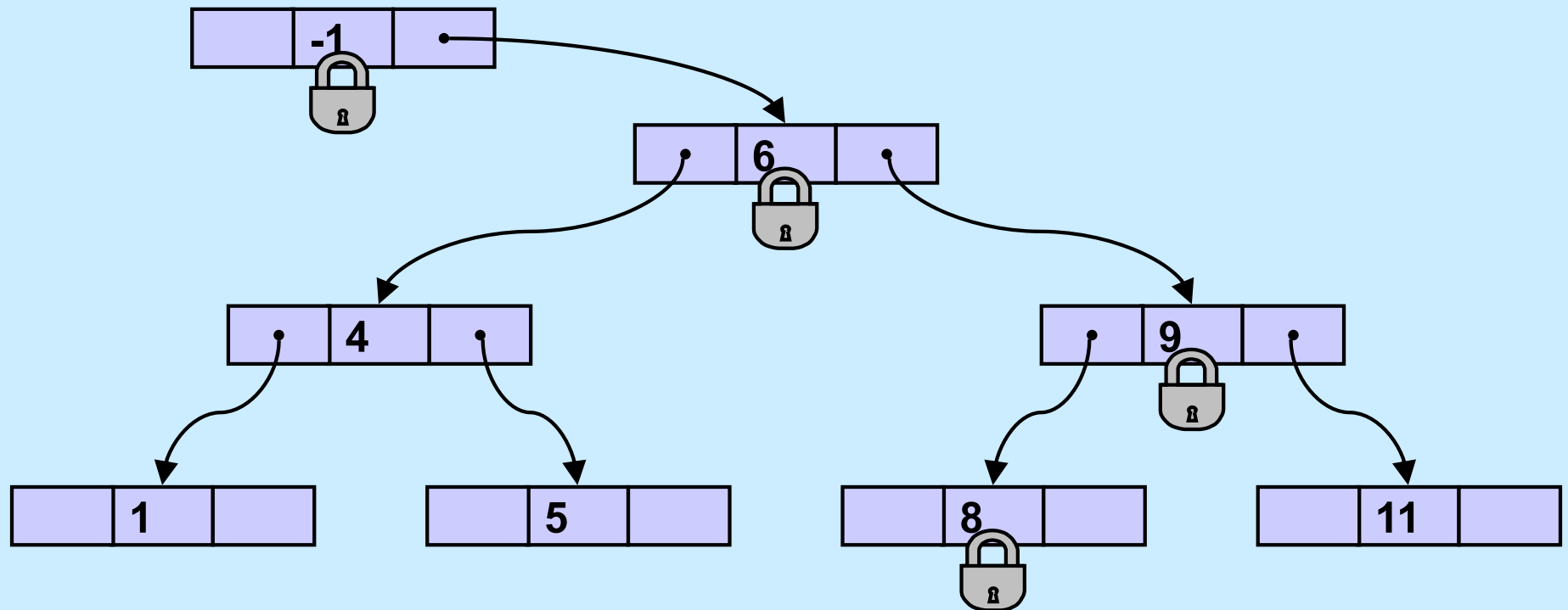
Binary Search Tree with Fine-Grained Synchronization II



Binary Search Tree with Fine-Grained Synchronization III



Doing It Right ...



C Code: Fine-Grained Search I

```
enum locktype {l_read, l_write};

#define lock(lt, lk) ((lt) == l_read)?
    pthread_rwlock_rdlock(lk):
    pthread_rwlock_wrlock(lk)

Node *search(int key,
    Node *parent, Node **parentp,
    enum locktype lt) {
    // parent is locked on entry
    Node *next;
    Node *result;
    if (key < parent->key) {
        if ((next = parent->lchild)
            == 0) {
            result = 0;
        } else {
            lock(lt, &next->lock);
            if (key == next->key) {
                result = next;
            } else {
                pthread_rwlock_unlock(
                    &parent->lock);
                result = search(key,
                    next, parentp, lt);
            }
        }
    }
    return result;
}
```

C Code: Fine-Grained Search II

```
} else {
    if ((next = parent->rchild)
        == 0) {
        result = 0;
    } else {
        lock(lt, &next->lock);
        if (key == next->key) {
            result = next;
        } else {
            pthread_rwlock_unlock(
                &parent->lock);
            result = search(key,
                next, parentpp, lt);
            return result;
        }
    }
}

if (parenttp != 0) {
    // parent remains locked
    *parenttp = parent;
} else
    pthread_rwlock_unlock(
        &parent->lock);
return result;
}
```

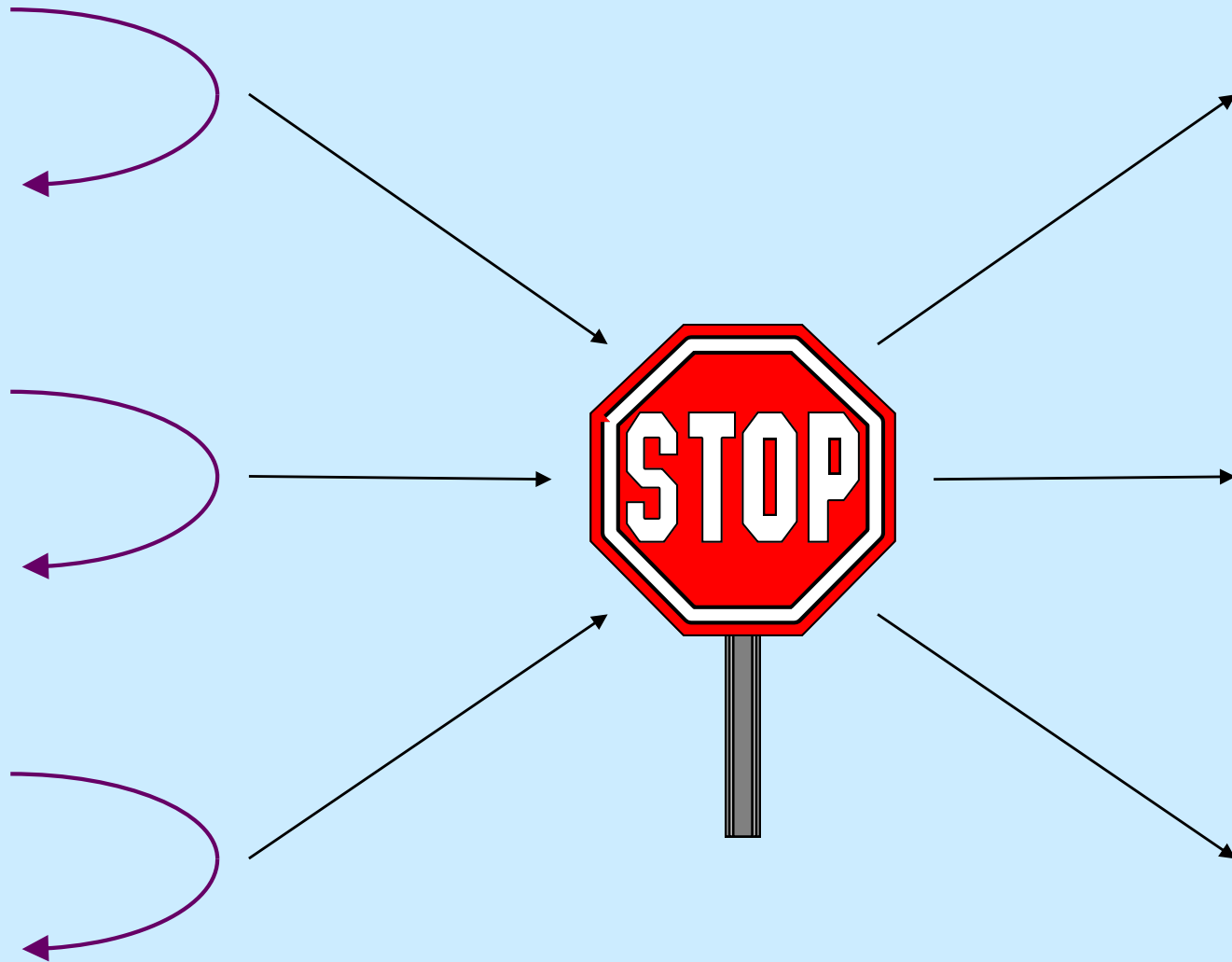
C Code: Add with Fine-Grained Synchronization I

```
int add(int key) {  
    Node *parent, *target, *newnode;  
    pthread_rwlock_wrlock(&head->lock);  
    if ((target = search(key, &head, &parent,  
        l_write)) != 0) {  
        pthread_rwlock_unlock(&target->lock);  
        pthread_rwlock_unlock(&parent->lock);  
        return 0;  
    }  
}
```

C Code: Add with Fine-Grained Synchronization II

```
newnode = malloc(sizeof(Node));
newnode->key = key;
newnode->lchild = newnode->rchild = 0;
pthread_rwlock_init(&newnode->lock, 0);
if (name < parent->name)
    parent->lchild = newnode;
else
    parent->rchild = newnode;
pthread_rwlock_unlock(&parent->lock);
return 1;
}
```

Barriers



A Solution?

```
pthread_mutex_lock(&m);  
if (++count == number) {  
    pthread_cond_broadcast(&cond_var);  
} else while (!(count == number)) {  
    pthread_cond_wait(&cond_var, &m);  
}  
pthread_mutex_unlock(&m);
```


How About This?

```
pthread_mutex_lock(&m);  
if (++count == number) {  
    pthread_cond_broadcast(&cond_var);  
    count = 0;  
} else while (!(count == number)) {  
    pthread_cond_wait(&cond_var, &m);  
}  
pthread_mutex_unlock(&m);
```

And This ...

```
pthread_mutex_lock(&m);  
if (++count == number) {  
    pthread_cond_broadcast(&cond_var);  
    count = 0;  
} else {  
    pthread_cond_wait(&cond_var, &m);  
}  
pthread_mutex_unlock(&m);
```

Quiz 1

Does it work?

- a) definitely
- b) probably
- c) rarely
- d) never

Barrier in POSIX Threads

```
pthread_mutex_lock(&m);  
if (++count < number) {  
    int my_generation = generation;  
    while(my_generation == generation) {  
        pthread_cond_wait(&waitQ, &m);  
    }  
} else {  
    count = 0;  
    generation++;  
    pthread_cond_broadcast(&waitQ);  
}  
pthread_mutex_unlock(&m);
```

More From POSIX!

```
int pthread_barrier_init(pthread_barrier_t *barrier,  
    pthread_barrierattr_t *attr,  
    unsigned int count);  
int pthread_barrier_destroy(  
    pthread_barrier_t *barrier);  
int pthread_barrier_wait(  
    pthread_barrier_t *barrier);
```

Why *cond_wait* is Weird ...

```
pthread_cond_wait(pthread_cond_t *c, pthread_mutex_t *m) {  
    pthread_mutex_unlock(m);  
    sem_wait(c->sem);  
    pthread_mutex_lock(m);  
}
```

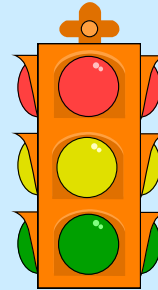
```
pthread_cond_signal(pthread_cond_t *c) {  
    sem_post(c->sem);  
}
```

Deviations

- **Signals**



vs.

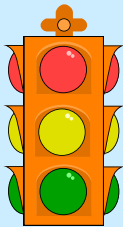


- **Cancellation**
 - tamed lightning

Signals



- who gets them?
 - who needs them?



- how do you respond to them?

Dealing with Signals

- **Per-thread signal masks**
- **Per-process signal vectors**
- **One delivery per signal**

Signals and Threads

```
int pthread_kill(pthread_t thread, int signo);
```

- thread equivalent of *kill*

```
int pthread_sigmask(int how,  
    const sigset_t *newmask,  
    sigset_t oldmask);
```

- thread equivalent of *sigprocmask*

Asynchronous Signals (1)

```
int main( ) {  
    void handler(int);  
    signal(SIGINT, handler);  
  
    ...  
  
}  
  
void handler(int sig) {  
    ...  
}
```

Asynchronous Signals (2)

```
int main( ) {  
    void handler(int);  
  
    signal(SIGINT, handler);  
  
    ...    // complicated program  
  
    printf("important message: "  
           "%s\n", message);  
  
    ...    // more program  
  
}
```

```
void handler(int sig) {  
  
    ...    // deal with signal  
  
    printf("equally important "  
           "message: %s\n", message);  
  
}
```

Quiz 2

```
int main( ) {  
    void handler(int);  
  
    signal(SIGINT, handler);  
  
    ...    // complicated program  
  
    pthread_mutex_lock(&mut);  
    printf("important message: "  
        "%s\n", message);  
    pthread_mutex_unlock(&mut);  
  
    ...    // more program  
}
```

```
void handler(int sig) {  
  
    ...    // deal with signal  
  
    pthread_mutex_lock(&mut);  
    printf("equally important "  
        "message: %s\n", message);  
    pthread_mutex_unlock(&mut);  
}
```

Does this work?

- a) yes**
- b) no**

Synchronizing Asynchrony

```
computation_state_t  state;
sigset_t  set;
int main( ) {
    pthread_t  thread;

    sigemptyset(&set);
    sigaddset(&set, SIGINT);
    pthread_sigmask(SIG_BLOCK,
        &set, 0);
    pthread_create(&thread, 0,
        monitor, 0);
    long_running_procedure( );
}
```

```
void *monitor(void *dummy) {
    int sig;
    while (1) {
        sigwait(&set, &sig);
        display(&state);
    }
    return(0);
}
```

Cancellation



Sample Code

```
void *thread_code(void *arg) {
    node_t *head = 0;
    while (1) {
        node_t *nodep;
        nodep = (node_t *)malloc(sizeof(node_t));
        if (read(0, &node->value,
                sizeof(node->value)) == 0) {
            free(nodep);
            break;
        }
        nodep->next = head;
        head = nodep;
    }
    return head;
}
```

pthread_cancel(thread);

Cancellation Concerns

- **Getting cancelled at an inopportune moment**
- **Cleaning up**

Cancellation State

- **Pending cancel**
 - `pthread_cancel(thread)`
- **Cancels enabled or disabled**
 - `int pthread_setcancelstate(
 {PTHREAD_CANCEL_DISABLE
 PTHREAD_CANCEL_ENABLE},
 &oldstate)`
- **Asynchronous vs. deferred cancels**
 - `int pthread_setcanceltype(
 {PTHREAD_CANCEL_ASYNCHRONOUS,
 PTHREAD_CANCEL_DEFERRED},
 &oldtype)`

Cancellation Points

- `aio_suspend`
- `close`
- `creat`
- `fcntl` (when `F_SETLCKW` is the command)
- `fsync`
- `mq_receive`
- `mq_send`
- `msync`
- `nanosleep`
- `open`
- `pause`
- `pthread_cond_wait`
- `pthread_cond_timedwait`
- `pthread_join`
- `pthread_testcancel`
- `read`
- `sem_wait`
- `sigwait`
- `sigwaitinfo`
- `sigsuspend`
- `sigtimedwait`
- `sleep`
- `system`
- `tcdrain`
- `wait`
- `waitpid`
- `write`

Cleaning Up

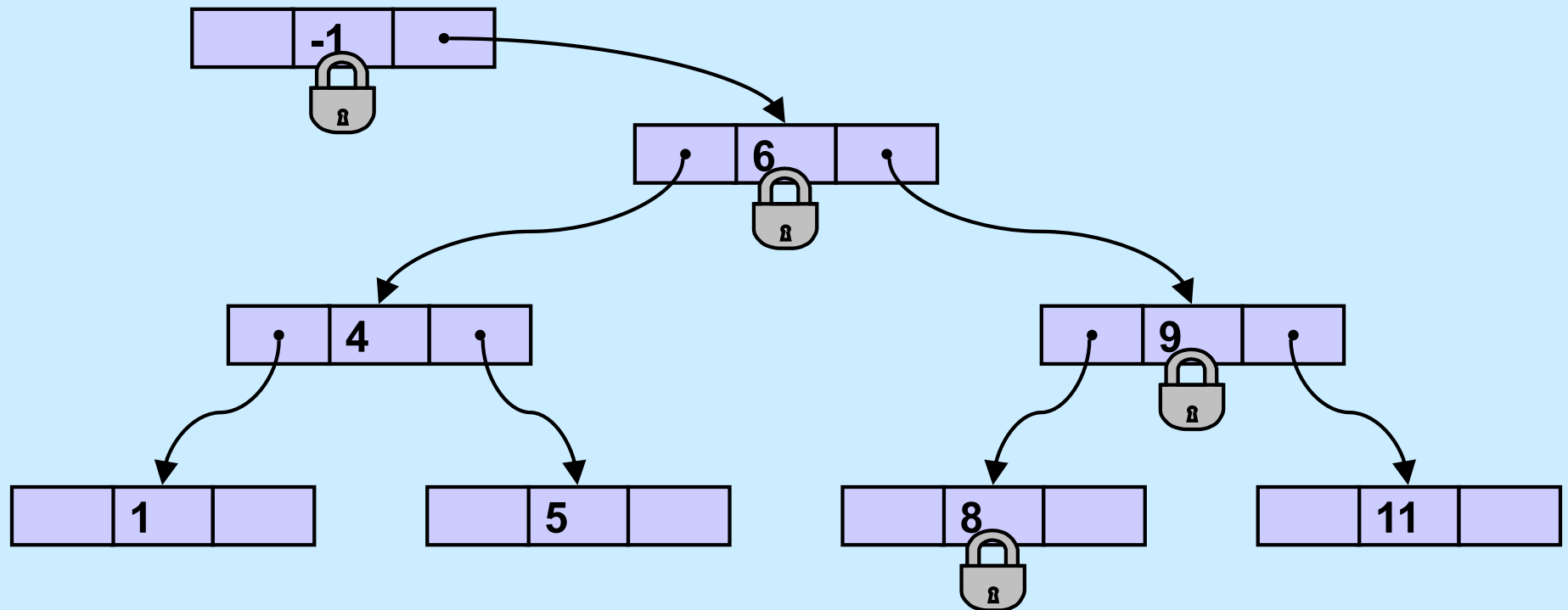
- **void** pthread_cleanup_push(**(void)** (*routine) (**void** *),
 void *arg)
- **void** pthread_cleanup_pop(**int** execute)

Sample Code, Revisited

```
void *thread_code(void *arg) {  
    node_t *head = 0;  
    pthread_cleanup_push(  
        cleanup, &head);  
    while (1) {  
        node_t *nodep;  
        nodep = (node_t *)  
            malloc(sizeof(node_t));  
        if (read(0, &node->value,  
            sizeof(node->value)) == 0) {  
            free(nodep);  
            break;  
        }  
        nodep->next = head;  
        head = nodep;  
    }  
    pthread_cleanup_pop(0);  
    return head;  
}
```

```
void cleanup(void *arg) {  
    node_t **headp = arg;  
    while(*headp) {  
        node_t *nodep = head->next;  
        free(*headp);  
        *headp = nodep;  
    }  
}
```

A More Complicated Situation ...



Start/Stop



- **Start/Stop interface**

```
void wait_for_start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    while(s->state == stopped)  
        pthread_cond_wait(&s->queue, &s->mutex);  
    pthread_mutex_unlock(&s->mutex);  
}  
  
void start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    s->state = started;  
    pthread_cond_broadcast(&s->queue);  
    pthread_mutex_unlock(&s->mutex);  
}
```

Start/Stop

- Start/Stop interface

```
void wait_for_start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    while(s->state == stopped)  
        pthread_cond_wait(&s->queue,  
                           &s->mutex);  
    pthread_mutex_unlock(&s->mutex);  
}  
  
void start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    s->state = started;  
    pthread_cond_broadcast(&s->queue);  
    pthread_mutex_unlock(&s->mutex);  
}
```



Quiz 3

You're in charge of designing POSIX threads. Should *pthread_cond_wait* be a cancellation point?

- a) no
- b) yes; cancelled threads must acquire mutex before invoking cleanup handler
- c) yes; but they don't acquire mutex

Start/Stop



- **Start/Stop interface**

```
void wait_for_start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    pthread_cleanup_push(  
        pthread_mutex_unlock, &s);  
    while (s->state == stopped)  
        pthread_cond_wait(&s->queue, &s->mutex);  
    pthread_cleanup_pop(1);  
}  
  
void start(state_t *s) {  
    pthread_mutex_lock(&s->mutex);  
    s->state = started;  
    pthread_cond_broadcast(&s->queue);  
    pthread_mutex_unlock(&s->mutex);  
}
```

Cancellation and Conditions

```
pthread_mutex_lock(&m);  
pthread_cleanup_push(pthread_mutex_unlock, &m);  
while(should_wait)  
    pthread_cond_wait(&cv, &m);  
  
// ... (code perhaps containing other cancellation points)  
  
pthread_cleanup_pop(1);
```