# CS 33

## Multithreaded Programming III

# Condition Variables

```
when (guard) [
  statement 1;
  …
  statement n;
]
```

```
pthread_mutex_lock(&mutex);
while(!guard)
  pthread_cond_wait(
     &cond_var, &mutex);
statement 1;
…
statement n;
pthread_mutex_unlock(&mutex);
```

```
// code modifying the guard:
…
```

```
pthread_mutex_lock(&mutex);
// code modifying the guard:
…
pthread_cond_broadcast(
    &cond_var);
pthread_mutex_unlock(&mutex);
```

# Set Up

```
int pthread_cond_init(pthread_cond_t *cvp,
    pthread_condattr_t *attrp)

int pthread_cond_destroy(pthread_cond_t *cvp)

int pthread_condattr_init(pthread_condattr_t *attrp)

int pthread_condattr_destroy(pthread_condattr_t *attrp)
```

# PC with Condition Variables (1)

```
typedef struct buffer {
   pthread_mutex_t m;
   pthread_cond_t  more_space;
   pthread_cond_t  more_items;
   int             next_in;
   int             next_out;
   int             empty;
   char            buf[BSIZE];
} buffer_t;
```

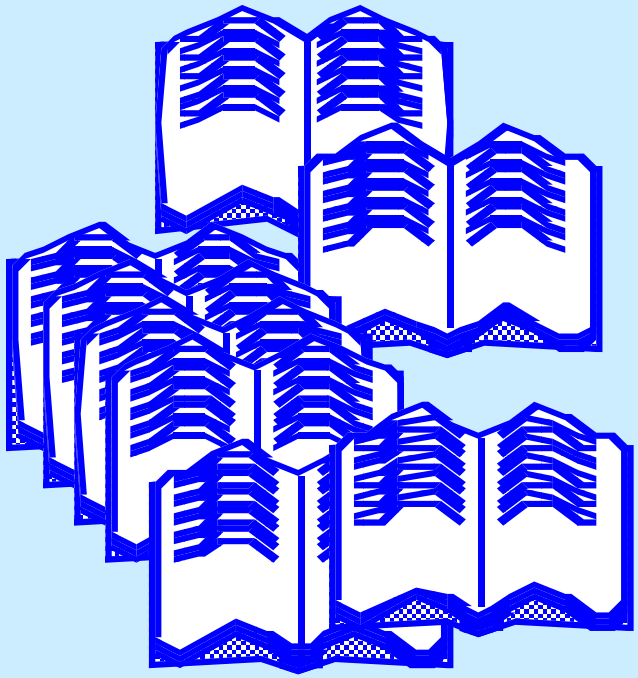
# PC with Condition Variables (2)

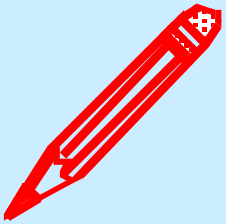
```
void produce(buffer_t *b,
     char item) {

  pthread_mutex_lock(&b->m);
  while (!(b->empty > 0))
    pthread_cond_wait(
        &b->more_space, &b->m);
  b->buf[b->nextin] = item;
  if (++(b->nextin) == BSIZE)
    b->nextin = 0;
  b->empty--;
  pthread_cond_signal(
     &b->more_items);
  pthread_mutex_unlock(&b->m);
}
```

```
char consume(buffer_t *b) {
  char item;
  pthread_mutex_lock(&b->m);
  while (!(b->empty < BSIZE))
    pthread_cond_wait(
        &b->more_items, &b->m);
  item = b->buf[b->nextout];
  if (++(b->nextout) == BSIZE)
    b->nextout = 0;
  b->empty++;
  pthread_cond_signal(
     &b->more_space);
  pthread_mutex_unlock(&b->m);
  return item;
}
```

# Readers-Writers Problem





# Pseudocode

```
reader( ) {
  when (writers == 0) [
    readers++;
  ]

  /* read */

  [readers--;]
}
```

```
writer( ) {
  when ((writers == 0) &&
      (readers == 0)) [
    writers++;
  ]

  /* write */

  [writers--;]
}
```

# Pseudocode with Assertions

```
reader( ) {
  when (writers == 0) [
    readers++;
  ]

  assert((writers == 0) &&
     (readers > 0));
  /* read */

  [readers--;]
}
```

```
writer( ) {
  when ((writers == 0) &&
     (readers == 0)) [
    writers++;
  ]

  assert((readers == 0) &&
     (writers == 1));
  /* write */

  [writers--;]
}
```

# Solution with POSIX Threads

```
reader( ) {
  pthread_mutex_lock(&m);
  while (!(writers == 0))
    pthread_cond_wait(
        &readersQ, &m);
  readers++;
  pthread_mutex_unlock(&m);
  /* read */
  pthread_mutex_lock(&m);
  if (--readers == 0)
    pthread_cond_signal(
        &writersQ);
  pthread_mutex_unlock(&m);
}
```

```
writer( ) {
  pthread_mutex_lock(&m);
  while(!((readers == 0) &&
       (writers == 0)))
    pthread_cond_wait(
        &writersQ, &m);
  writers++;
  pthread_mutex_unlock(&m);
  /* write */
  pthread_mutex_lock(&m);
  writers--;
  pthread_cond_signal(
       &writersQ);
  pthread_cond_broadcast(
     &readersQ);
  pthread_mutex_unlock(&m);
}
```

# Quiz 1

**If a thread calls *writer*, will it eventually return from *writer* (assuming well behaved threads)?**

a) yes, always

b) it will usually return, but it's possible that it will not return

c) it might return, but it's highly likely that it will never return

d) no, never

# New Pseudocode

```
reader( ) {
  when (writers == 0) [
    readers++;
  ]

  /* read */

  [readers--;]
}
```

```
writer( ) {
  [writers++;]
  when ((readers == 0) &&
       (active_writers == 0)) [
    active_writers++;
  ]

  /* write */

  [writers--;
  active_writers--;]
}
```

# Improved Reader

```
reader( ) {
  pthread_mutex_lock(&m);

  while (!(writers == 0)) {
    pthread_cond_wait(
          &readersQ, &m);
  }
  readers++;

  pthread_mutex_unlock(&m);

  /* read */

  pthread_mutex_lock(&m);

  if (--readers == 0)
    pthread_cond_signal(
          &writersQ);

  pthread_mutex_unlock(&m);
}
```

# Improved Writer

```
writer( ) {
  pthread_mutex_lock(&m);

  writers++;
  while (!((readers == 0) &&
        (active_writers == 0))) {
    pthread_cond_wait(
          &writersQ, &m);
  }
  active_writers++;

  pthread_mutex_unlock(&m);

  /* write */

  pthread_mutex_lock(&m);

  writers--;
    active_writers--;
  if (writers)
    pthread_cond_signal(
          &writersQ);
  else
    pthread_cond_broadcast(
          &readersQ);

  pthread_mutex_unlock(&m);
}
```

# Quiz 2

**If a thread calls *reader*, will it eventually return from *reader* (assuming well behaved threads)?**

a) yes, always

b) it will usually return, but it's possible that it will not return

c) it might return, but it's highly likely that it will never return

d) no, never

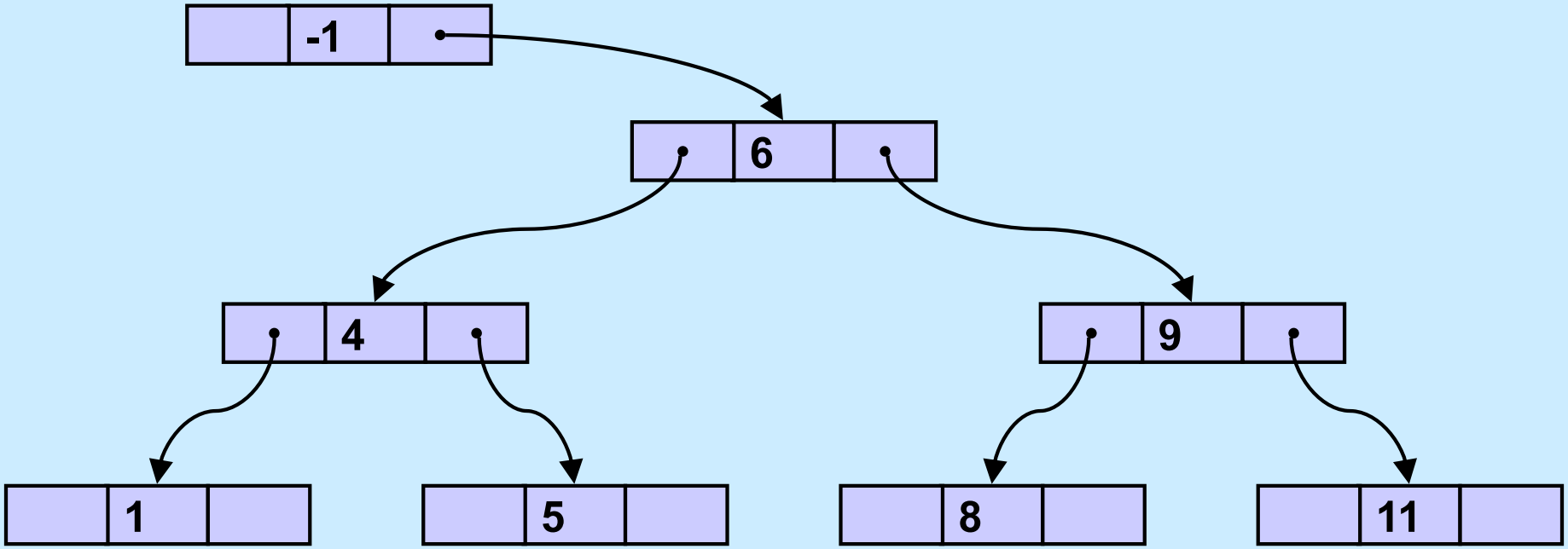
# New, From POSIX!

```
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);
```

# Quiz 3

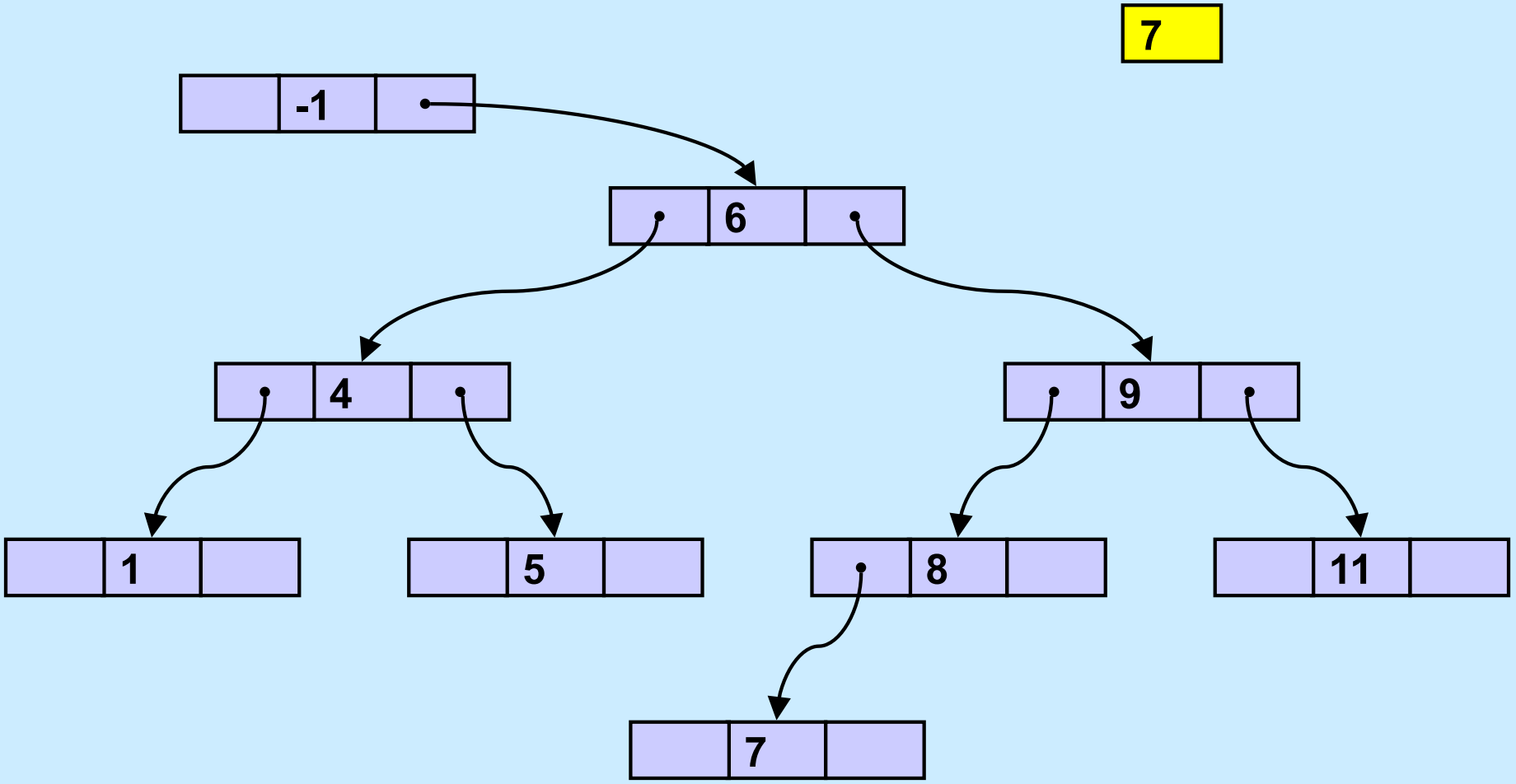
- **Missing in the *rwlock* API is a function to "upgrade" a readers lock into a writers lock. It's not included because**
  - **a) it's rarely needed, so there's no point to including it**
  - **b) the same effect could be achieved by unlocking the readers lock, then taking a writers lock**
  - **c) using such a function would likely result in deadlock**

# Binary Search Tree



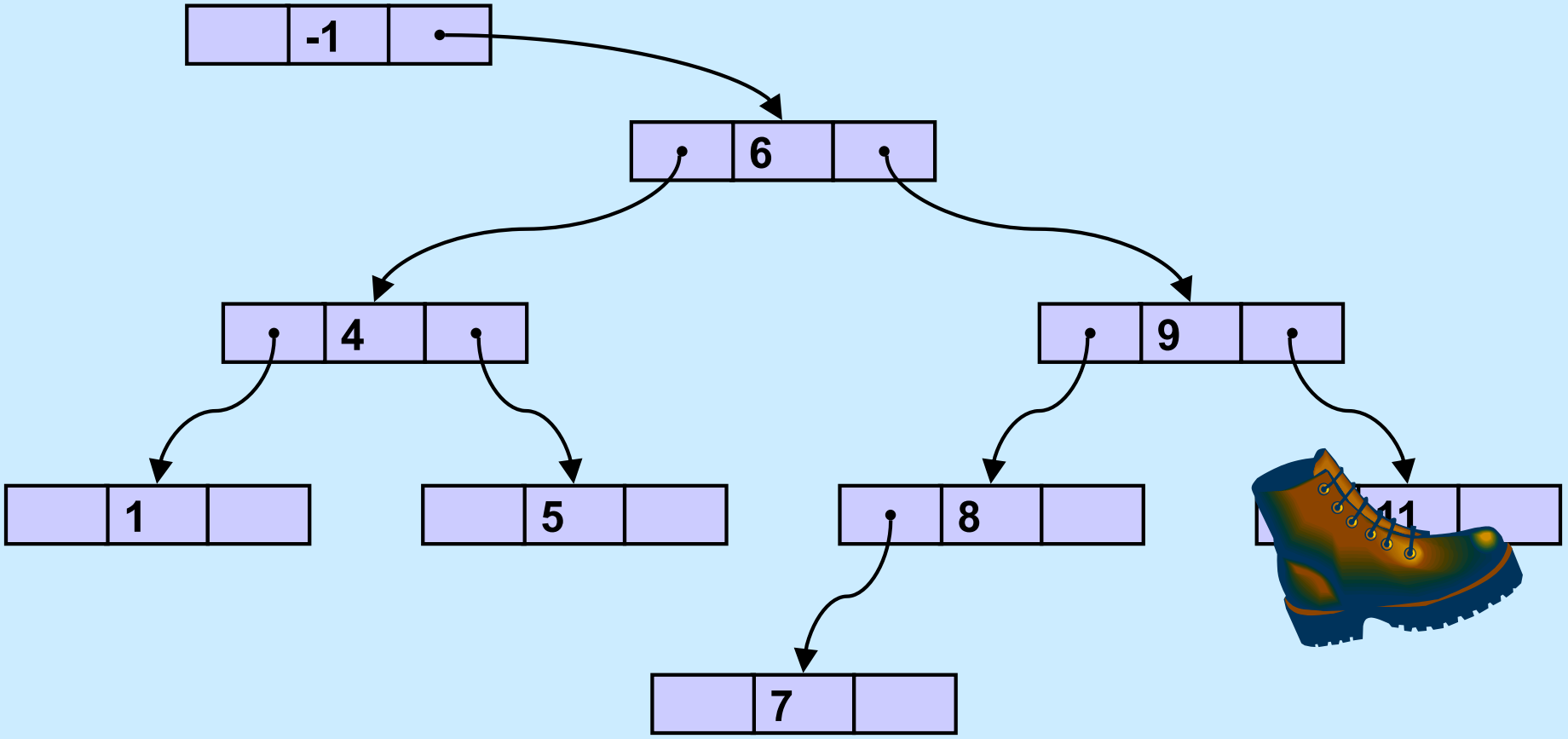

 

# Binary Search Tree: Insertion



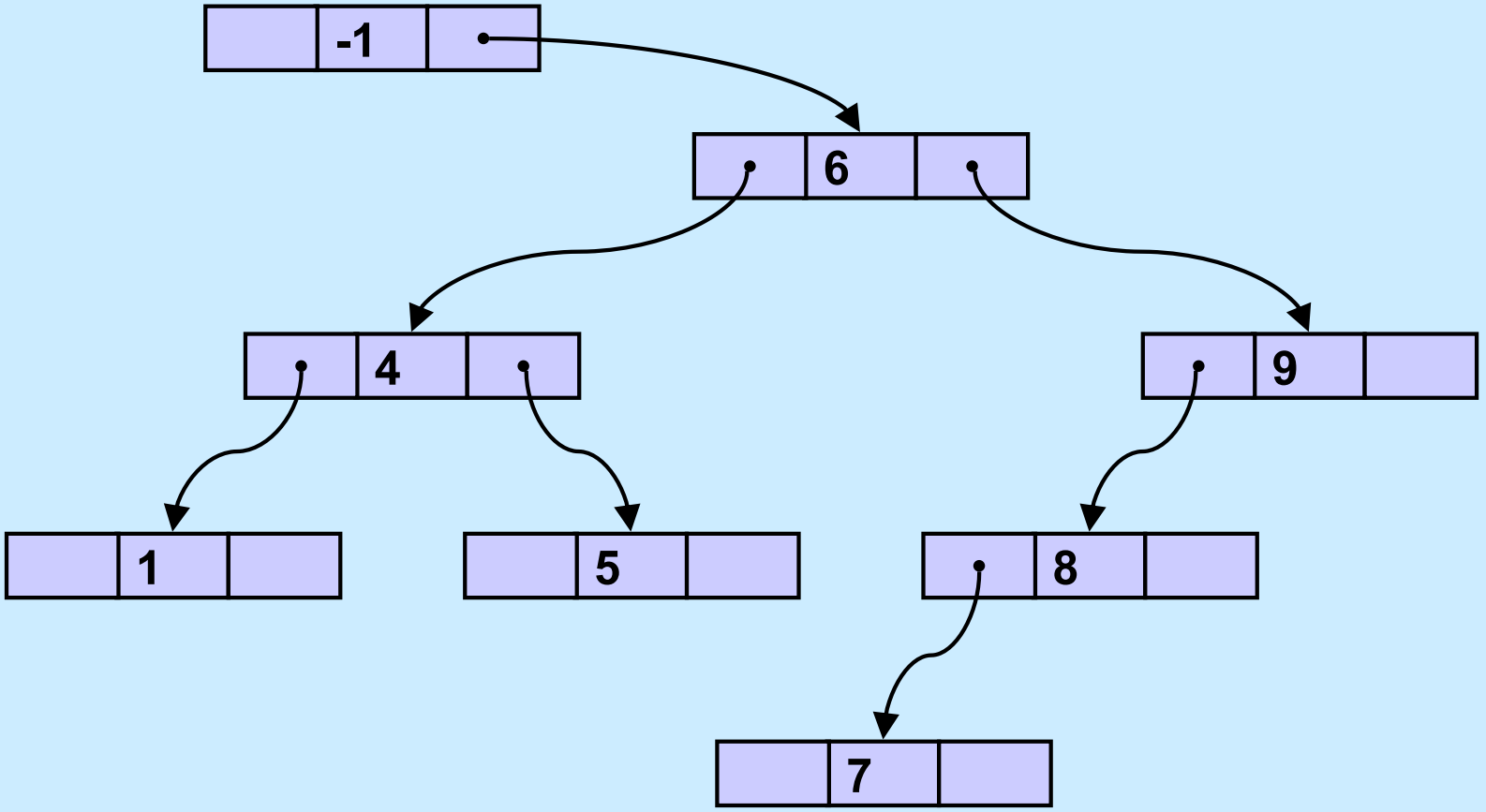

 

# Binary Search Tree: Deletion of Leaf



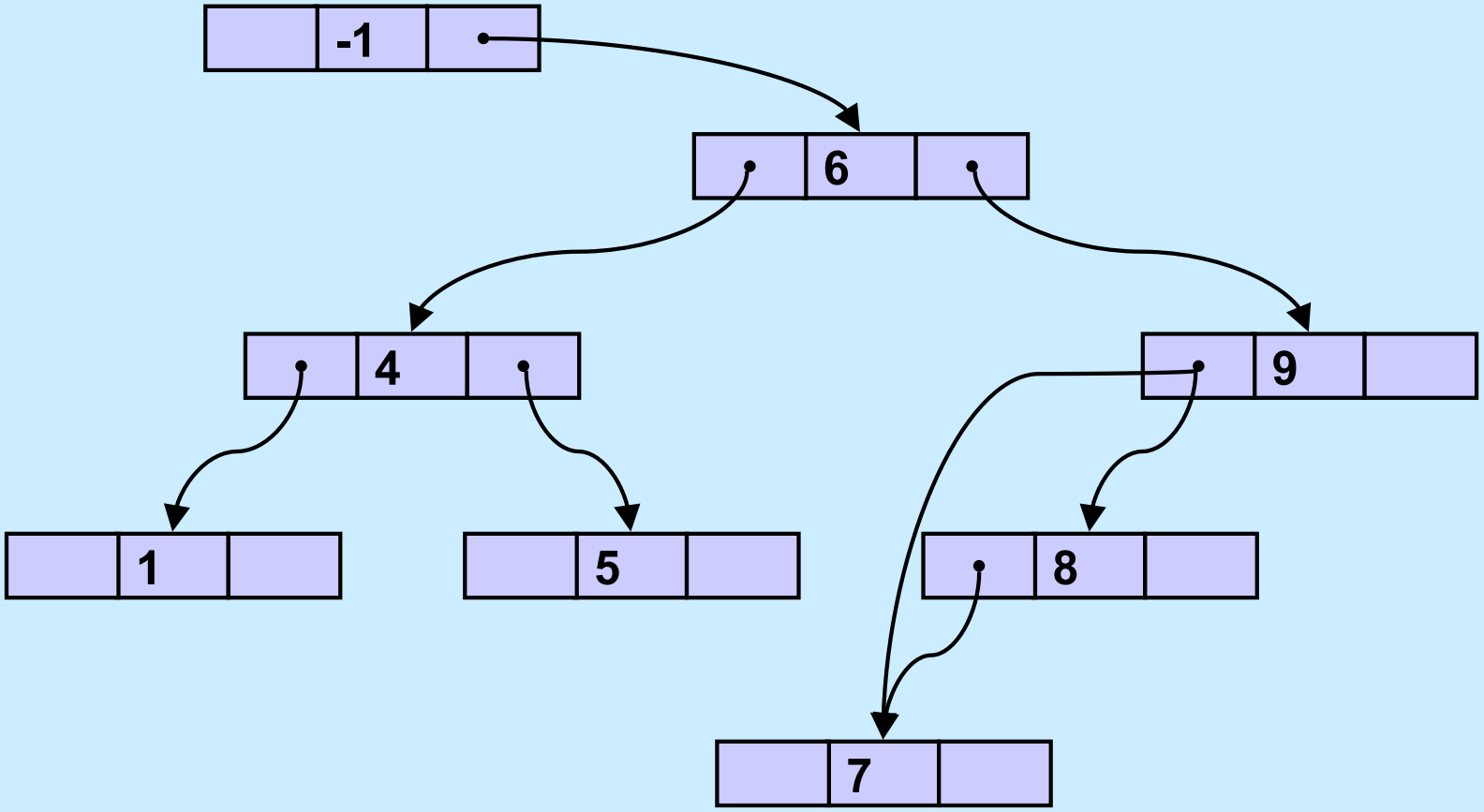

 

# Binary Search Tree: Deletion of Leaf



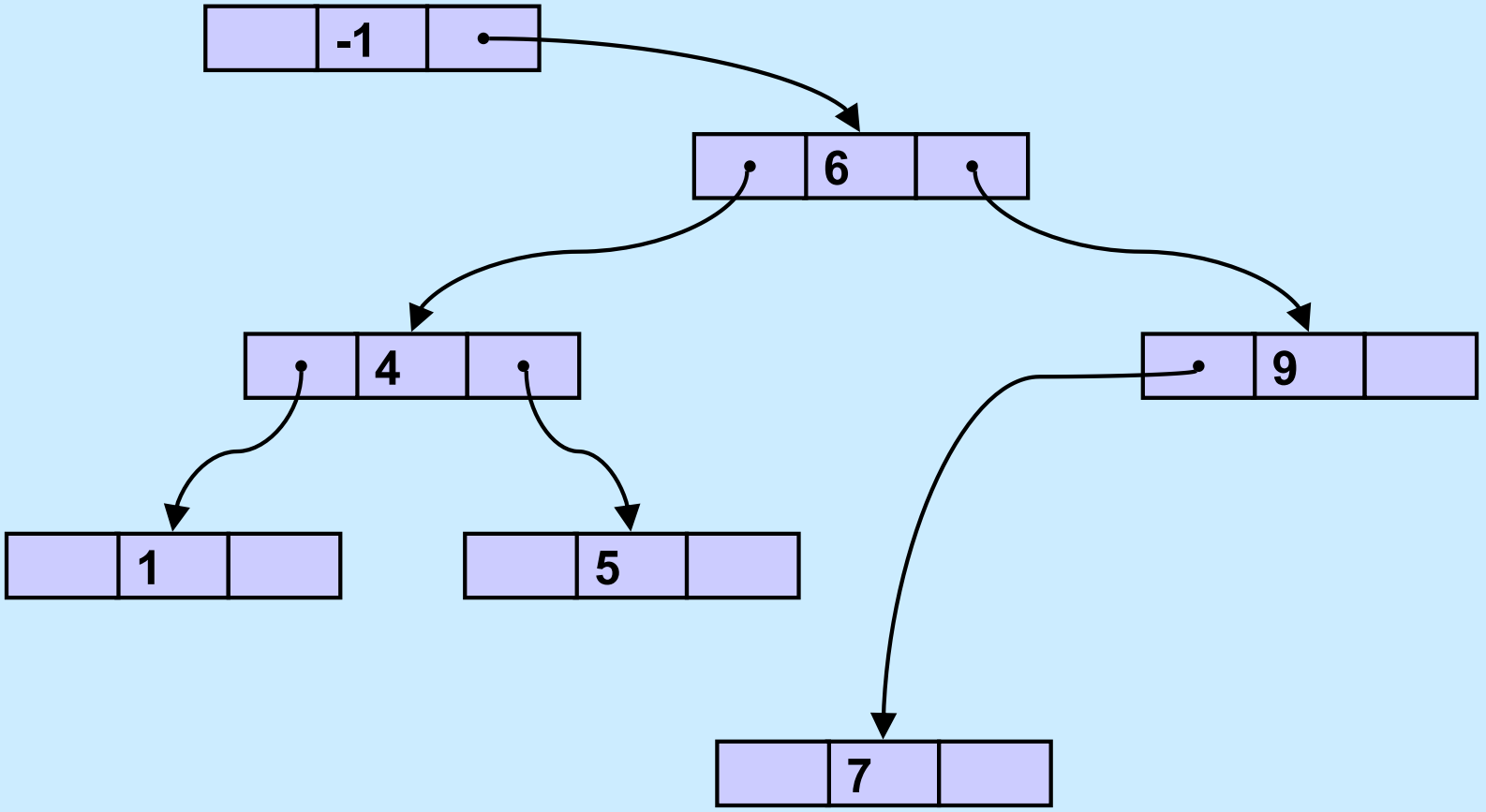

 

# Binary Search Tree: Deletion of Node with One Child



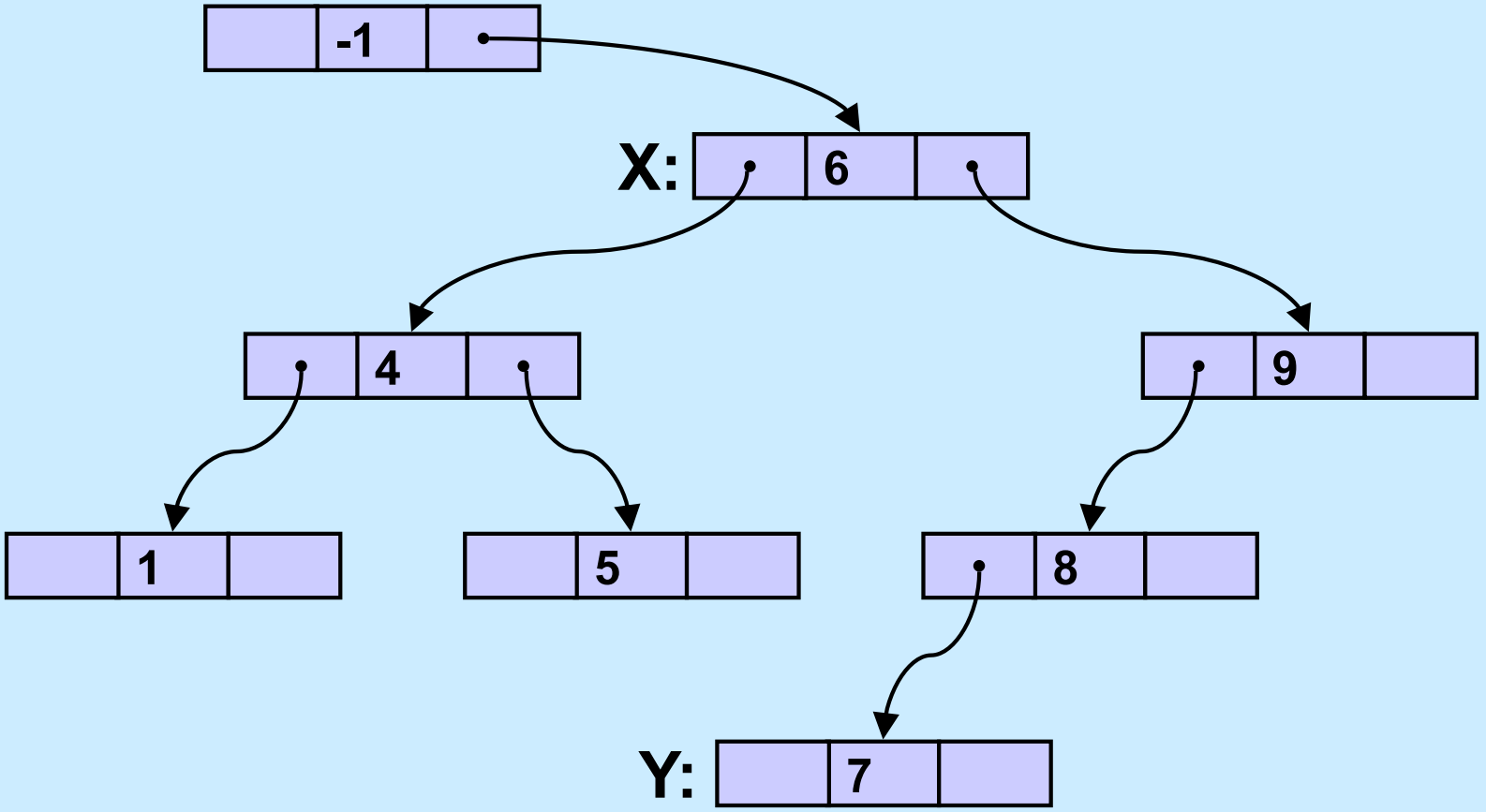

 

# Binary Search Tree: Deletion of Node with One Child



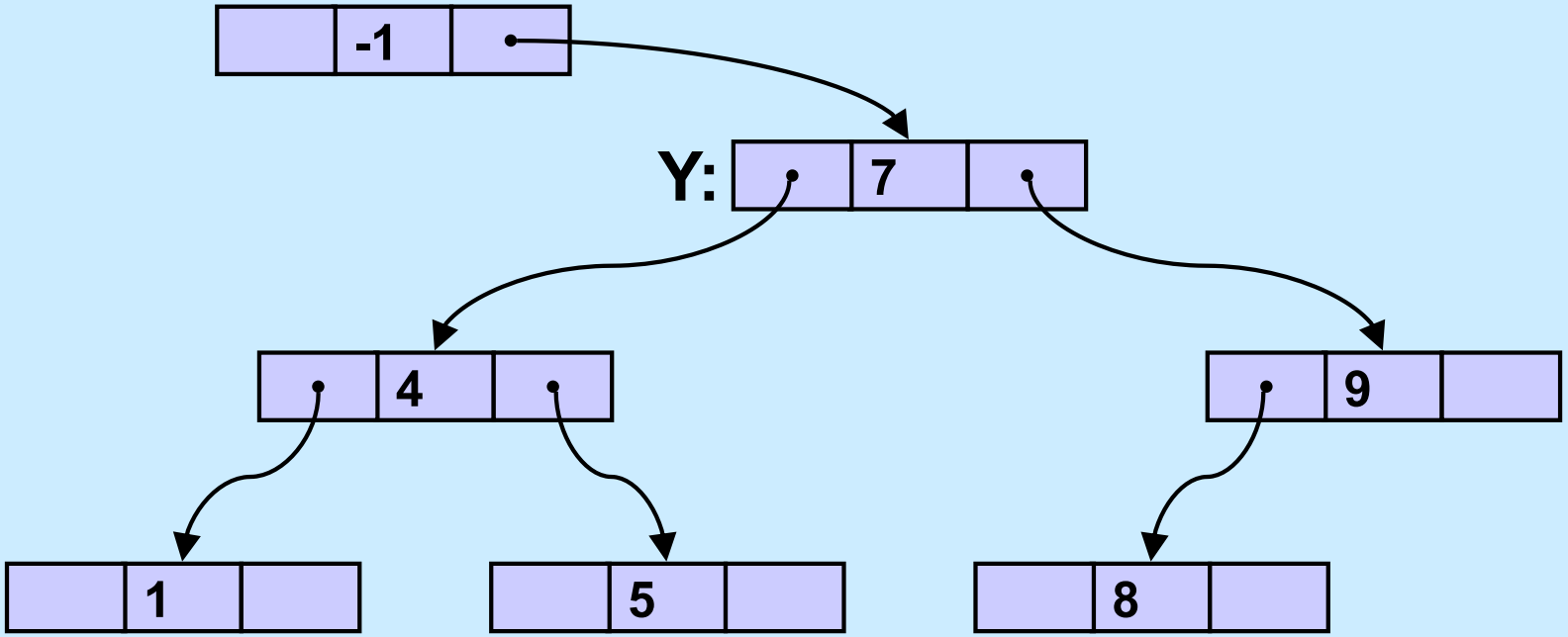

 

# Binary Search Tree: Deletion of Node with Two Children



# Binary Search Tree: Deletion of Node with Two Children



# C Code: Search

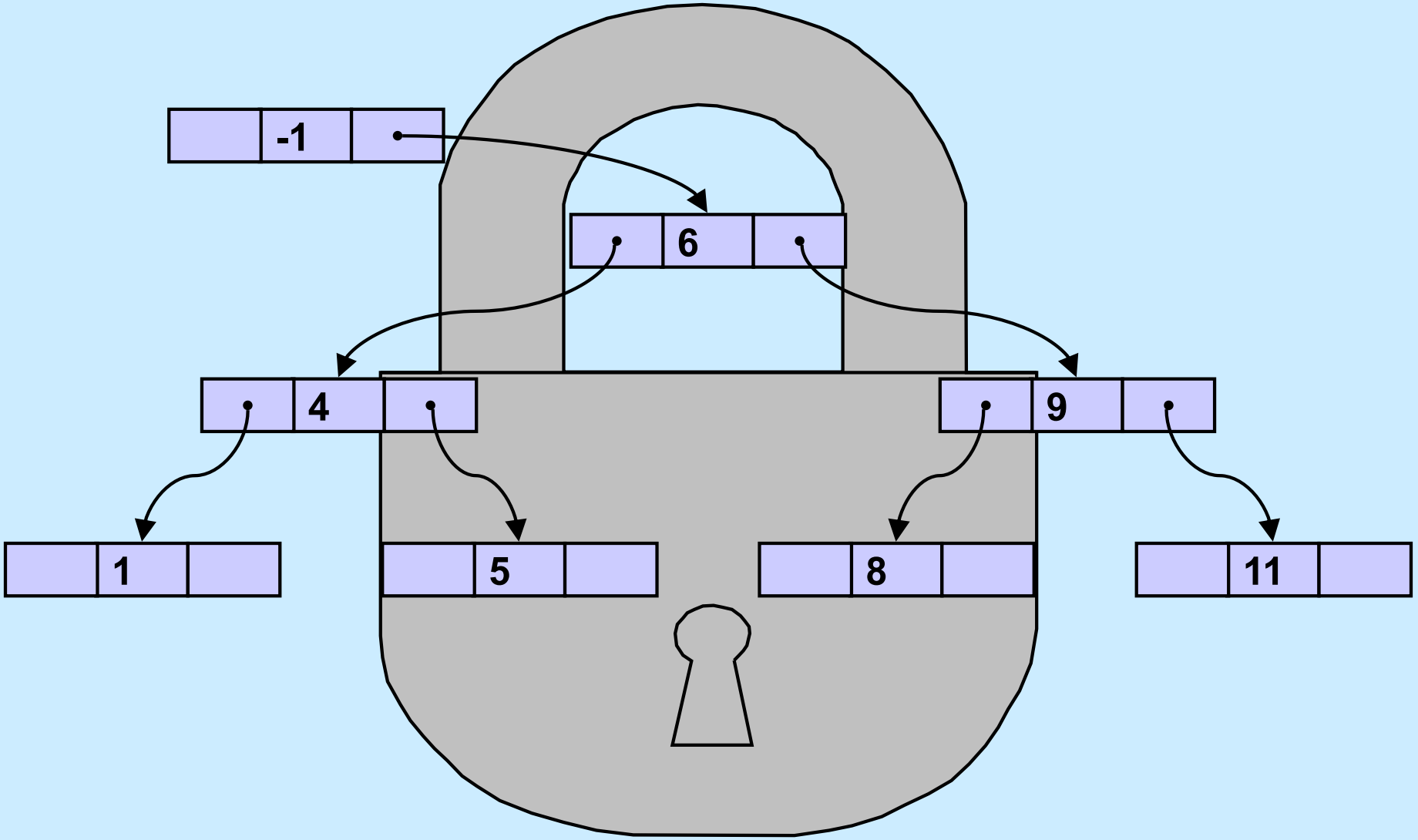
```
Node *search(int key,
    Node *parent, Node **parentp) {
  Node *next;
  Node *result;
  if (key < parent->key) {
    if ((next = parent->lchild)
        == 0) {
      result = 0;
    } else {
      if (key == next->key) {
        result = next;
      } else {
        result = search(key,
     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

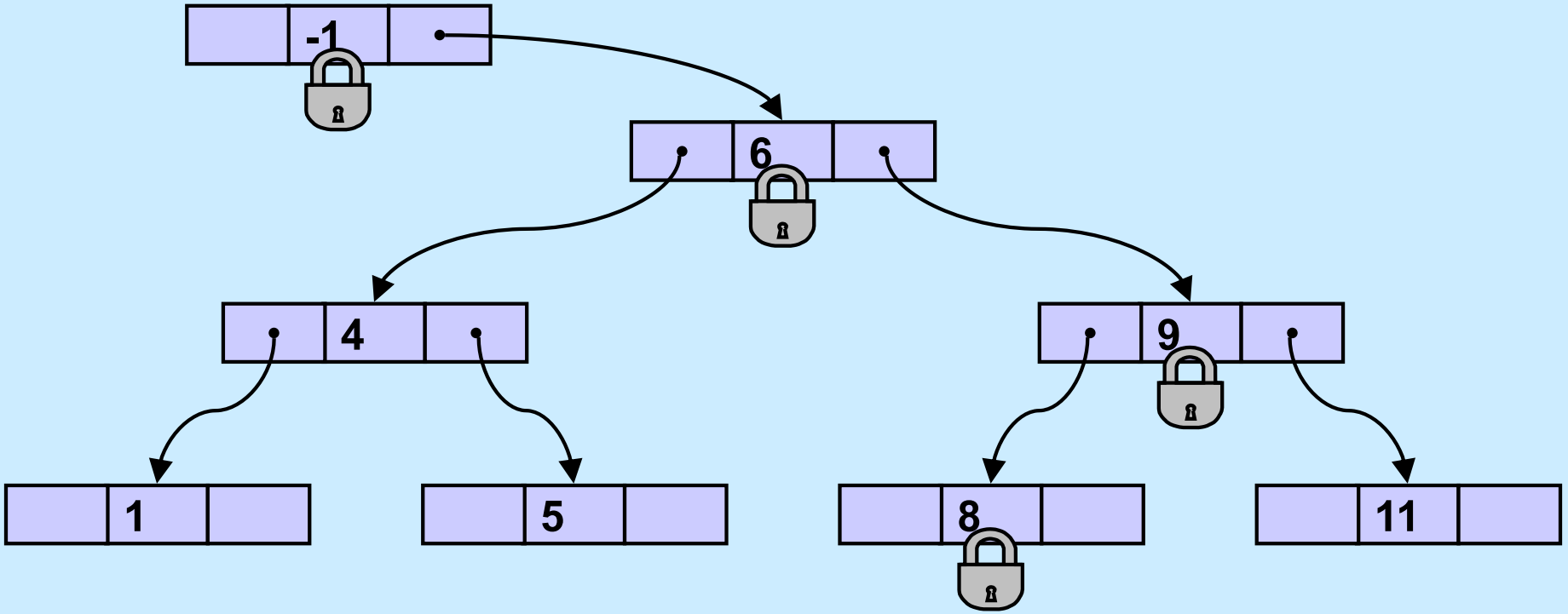
# Binary Search Tree
## with Coarse-Grained Synchronization



# C Code: Add
## with Coarse-Grained Synchronization

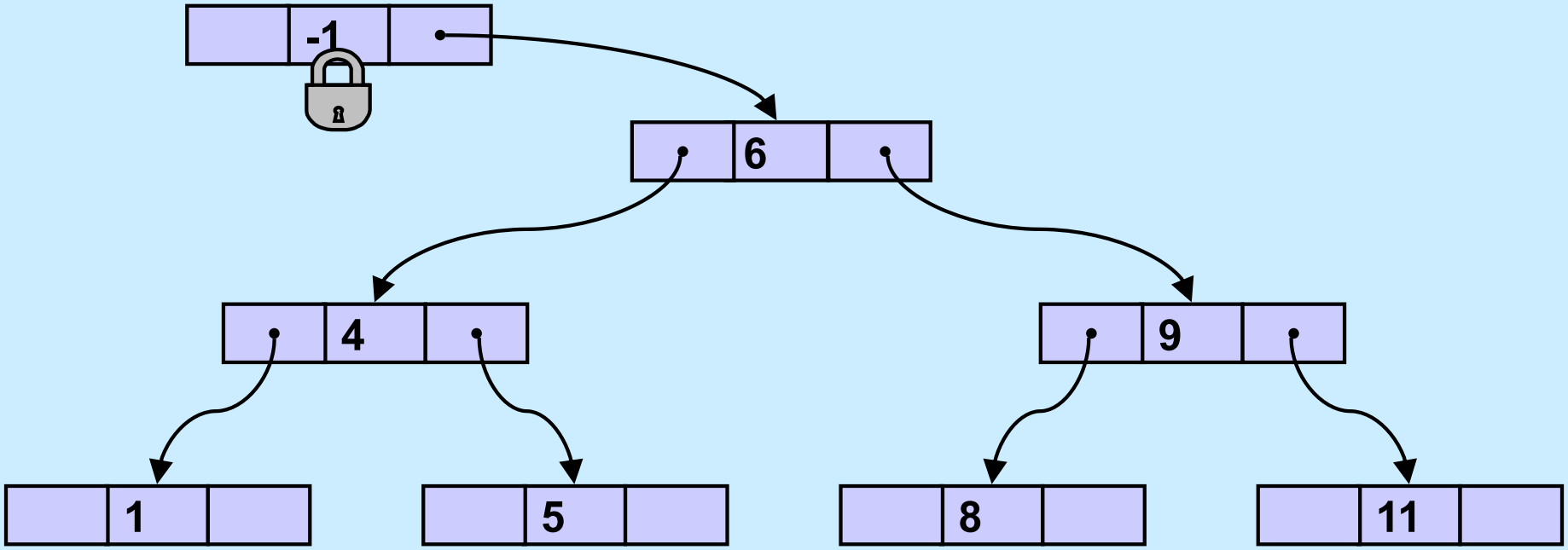
```
int add(int key) {
  Node *parent, *target, *newnode;
  pthread_rwlock_wrlock(&tree_lock);
  if ((target = search(key, &head, &parent)) != 0) {
    pthread_rwlock_unlock(&tree_lock);
    return 0;
  }
  newnode = malloc(sizeof(Node));
  newnode->key = key;
  newnode->lchild = newnode->rchild = 0;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



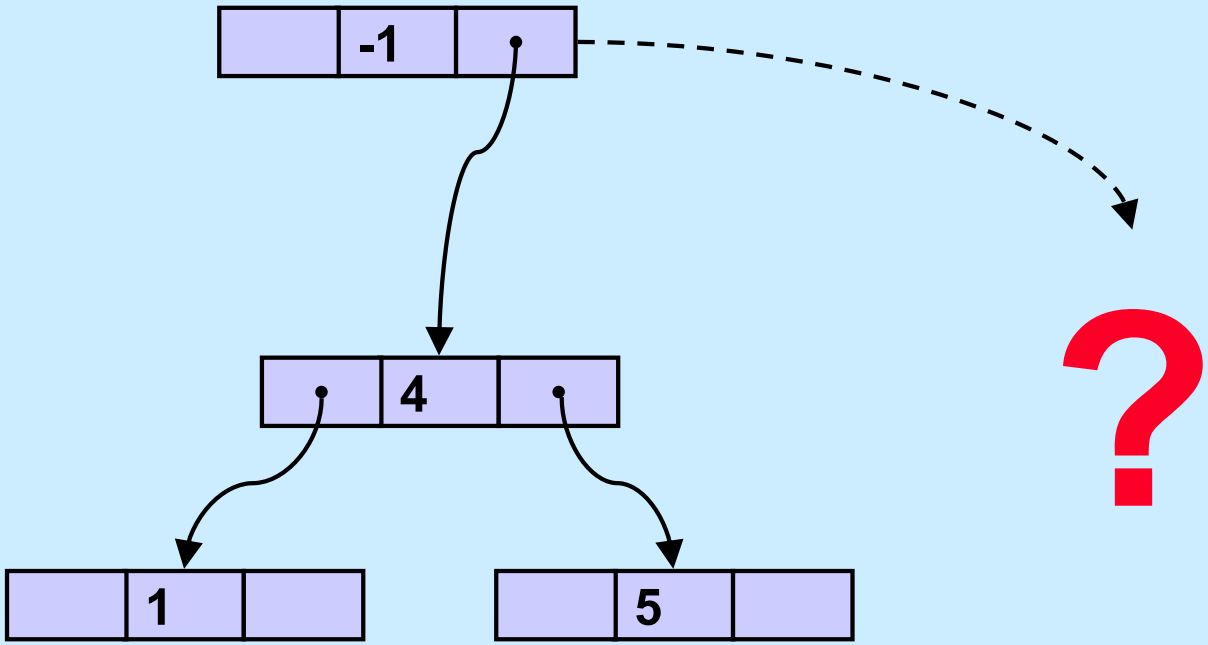

 

# Binary Search Tree
## with Fine-Grained Synchronization II

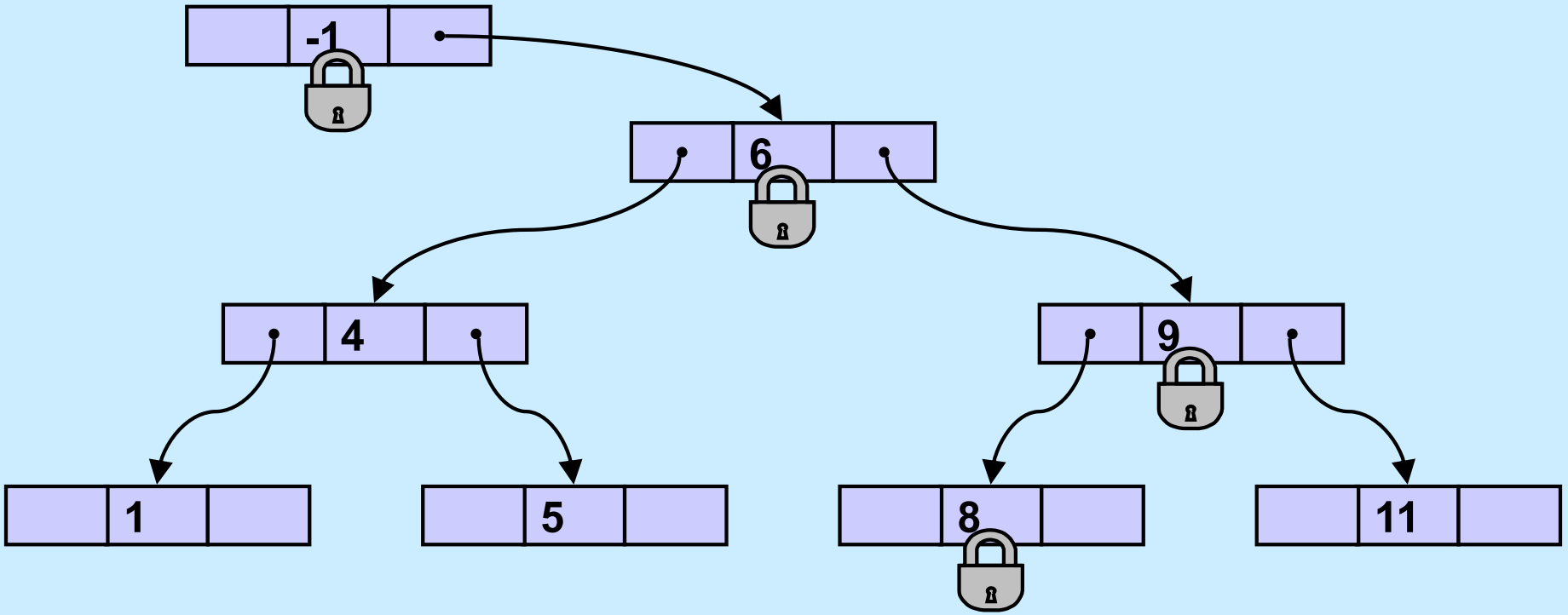


# Binary Search Tree
## with Fine-Grained Synchronization III



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

# Quiz 4

**The search function takes read locks if the purpose of the search is for a query, but takes write locks if the purpose is for an add or a delete. Would it make sense for it always to take read locks until it reaches the target of the search, then take a write lock just for that target?**

a) **Yes, since doing so allows more concurrency**

b) **No, it would work, but there would be no increase in concurrency**

c) **No, it would not work**

# 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;
}
```

# Quiz 5

**The add function calls malloc. Could we use the malloc that you'll finish by next Monday for this, or do we need a different one that's safe for use in multithreaded programs?**

a) Since the calling thread has a write lock on the parent of the new node, it's safe to call the standard malloc

b) Even if the calling thread didn't have a write lock on the parent, it would be safe to call the standard malloc

c) We will need a new malloc, one that's safe for use in multithreaded programs