Lecture 16. Writing Efficient Programs

- **Is n a prime?**

```
int isprime(int n) {
	if (n > 2) {
		int i, m = n/2;
		for (i = 2; i < m; i++)
			if (n%i == 0)
				return 0;
	}
	return 1;
}

int main(int argc, char *argv[]) {
	int i;

	for (i = 1; i < argc; i++) {
		int n;
		sscanf(argv[i], "%d", &n);
		if (isprime(n))
			printf("%d is a prime\n", n);
		else
			printf("%d is not a prime\n", n);
	}
	return 0;
}
```

```
% lcc isprime.c
% a.out 2147483647
...
```

- **2147483647 is a prime, but `isprime` takes 1073741823 iterations to check!**

Use a Better Algorithm

- **Observations:**

  Need to check only odd integers

  If n $= a \times b$, then either *a* or *b* must be $< \sqrt{n} + 1$

```
#include <math.h>

int isprime(int n) {
    if (n > 2 && n%2 != 0) {
        int i, m = sqrt(n) + 1;
        for (i = 3; i < m; i += 2)
            if (n%i == 0)
                return 0;
    }
    return 1;
}

% lcc isprime2.c
% a.out 2147483647
2147483647 is a prime
```

≈23169 iterations

- **Better algorithms make programs faster, not microscopic code hacks**
- **Programs must be fast enough, not necessarily as fast as possible**
- **Don't sacrifice clarity for speed**

Searching

- **A small ‘database’ problem: Maintain a list of names; lookup ‘queries,’ adding the new names, if necessary**

```
int main(int argc, char *argv[]) {
    int i;
    char buf[128];

    ptr = emalloc(size*sizeof (char *));
    ptr[0] = NULL;
    while (scanf("%s", buf) == 1)
        lookup(buf);
    for (i = 1; i < argc; i++) {
        int k = lookup(argv[i]);
        printf("%d\t%s\n", k, argv[i]);
    }
    printf("\n");
    for (i = 0; ptr[i] != NULL; i++)
        printf("%d\t%s\n", i, ptr[i]);
    return 0;
}
```

```
% lcc -I/u/cs126/include lookup.c /u/cs126/lib/libmisc.a
% a.out drh appel <names
3525    drh
794     appel
…
14210   zzwang
```

Searching, cont'd

- **We know a good algorithm for searching — binary search (see page 10-3)**

```
int bsearch(char *x[], int lb, int ub, char *q) {
    if (lb <= ub) {
        int m = (lb + ub)/2;
        int cond = strcmp(x[m], q);
        if (cond < 0)
            return bsearch(x, m + 1, ub, q);
        else if (cond > 0)
            return bsearch(x, lb, m - 1, q);
        else
            return m;
    } else
        return -1;
}
```

see page 6-4 for `strcmp`

- **`ptr[0`..`count-1]` holds the names in ascending order; `ptr[count]` is `NULL`**

```
int count = 0;
char **ptr;

int lookup(char *name) {
    int k = bsearch(ptr, 0, count - 1, name);

    if (k == -1)
        k = insert(strsave(name));
    return k;
}
```

Cost of Binary Search

- **Counting *comparisons* — calls to `strcmp` in this version of `bsearch` — is a good measure of the cost of binary search**

- **Each recursive call cuts the problem in *half*, so the cost to search *N* names is**

$$C_N = C_{N/2} + 1 = C_{N/4} + 1 + 1 = \dots$$

Suppose $N = 2^n$, then

$$C_{2^n} = C_{2^{n-1}} + 1 = C_{2^{n-2}} + 1 + 1 = \dots = C_1 + 1 + \dots + 1 = n$$

$$C_N = \log_2 N = \lg N$$

Even for huge *N*, lg *N* is small (conversely, even for small *n*, 2^n is huge…)

N	**lg *N***
10	**4**
100	**7**
1,000	**10**
10,000	**14**
100,000	**17**
1,000,000	**20**
10^k	$\approx 3.129 \times k$

- **Bottom line: Binary search, and other lg *N* algorithms, are *fast***

Inserting Names

- **To keep the names in ascending order, `insert(q)`**

  Expands the array, if necessary

  Slides `ptr[k..count-1]` down into `ptr[k+1..count]` where `ptr[k]` > `q`

  Stores `q` in `ptr[k]`, increments `count` and sets `ptr[count]` to `NULL`

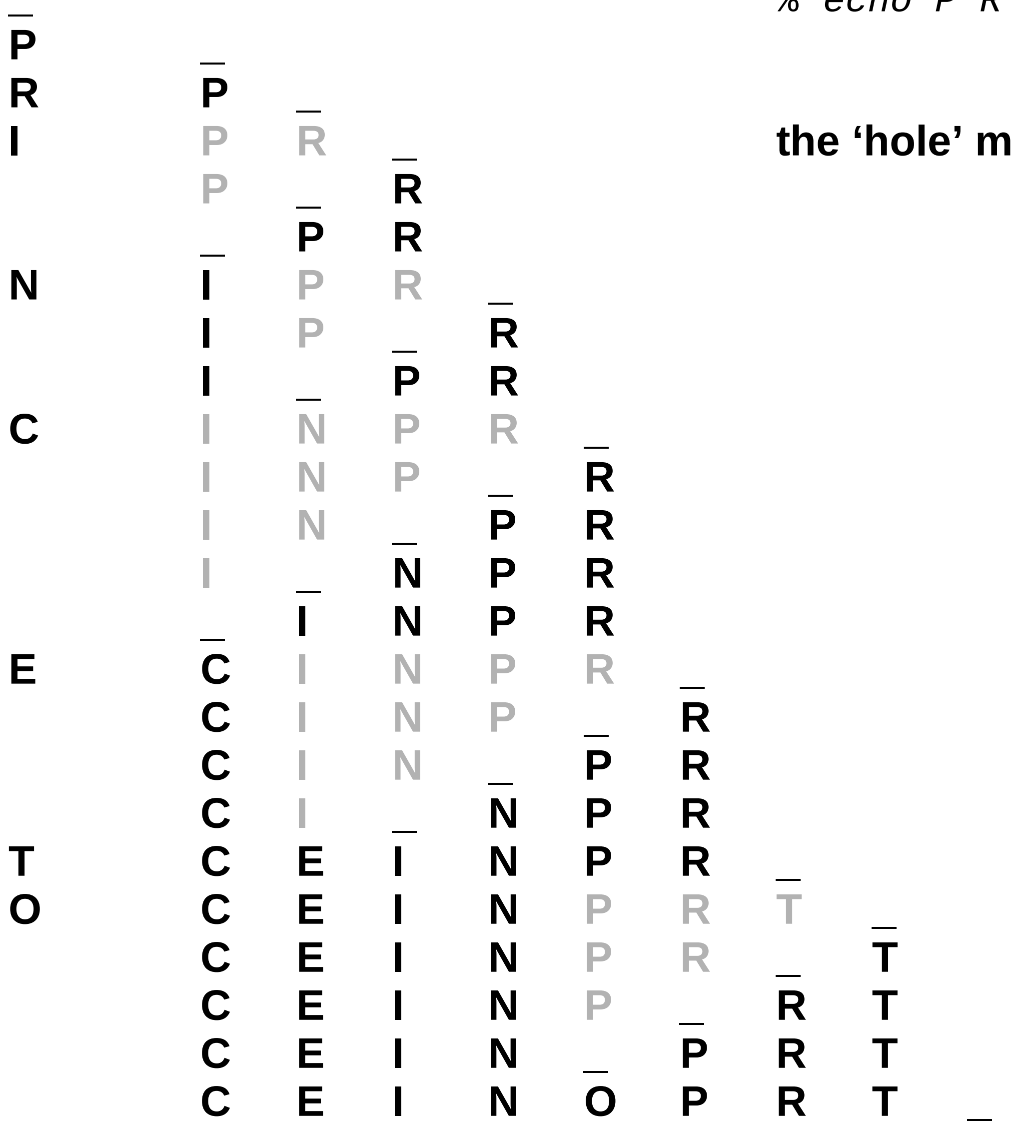
```
int size = 1;

int insert(char *q) {
	int k;

	if (count + 1 >= size) {
		size *= 2;
		ptr = erealloc(ptr, size*sizeof (char *));
	}
	for (k = count; k > 0 && strcmp(ptr[k-1], q) > 0; k--)
		ptr[k] = ptr[k-1];
	ptr[k] = q;
	ptr[++count] = NULL;
}
```

- **Oh oh… If the array holds *N* names, insert could take *N* comparisons**

insert in Action



`% echo P R I N C E T O N | a.out`

the 'hole' moves over dimmed letters

Binary Search Trees

- **Different representations have different costs**

	Search	**Insertion**	**Deletion**
Array	**fast**	**slow**	**slow**
Linked list	**slow: ≈*N***	**fast w/search** **slow w/o search**	**fast w/search** **slow w/o search**
Binary tree	***fast*: ≈*lg N***	***fast***	***fast***

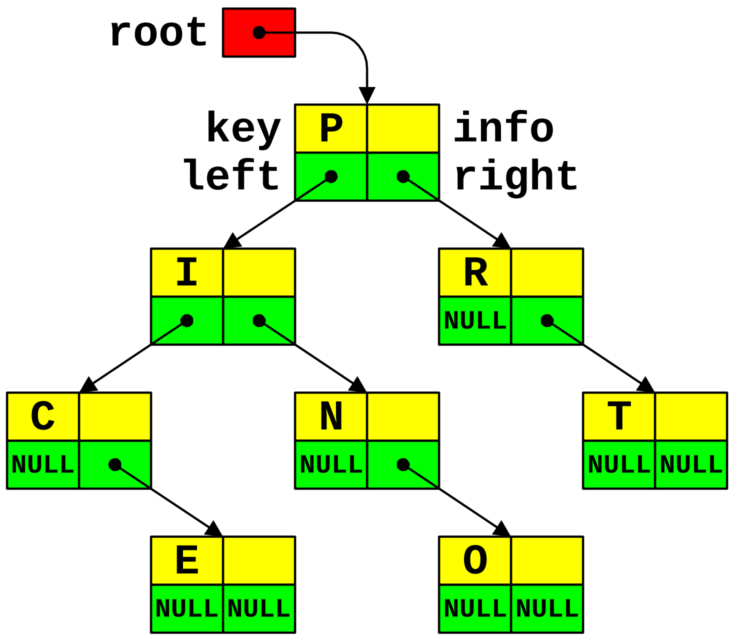
- **In a binary search tree**

```
struct node {
    char *key;
    int info;
    struct node *left, *right;
};
```

Names in the *left* subtree are < than the name in the *root*

Names in *right* subtree are ≥ the name in the root

Holds for any node in the tree

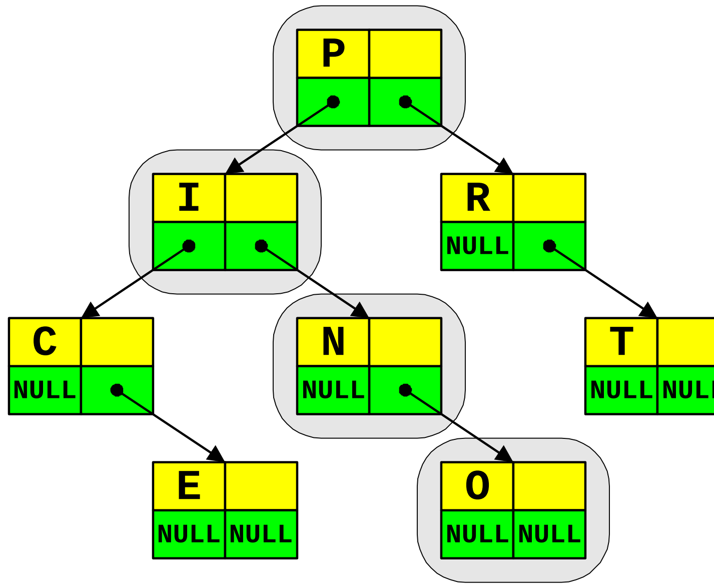


Searching in Binary Trees

- **To search for q in a binary search tree, start with `tree` = `root`**

  1. **If `tree` is `NULL`, the search fails — an important boundary condition**
  2. **If q < `tree->key`, search the *left* subtree**
  3. **If q > `tree->key`, search the *right* subtree**
  4. **q must be equal to `tree->key`**

```
struct node *search(struct node *tree, char *q) {
    if (tree != NULL) {
        int cond = strcmp(q, tree->key);
        if (cond < 0)
            return search(tree->left,  q);
        else if (cond > 0)
            return search(tree->right, q);
        else
            return tree;
    } else
        return NULL;
}
```



- **Cost of searching in *balanced* binary trees is the same as for binary search in arrays — lg *N***

- **It's possible to keep trees balanced during insertion; take COS 226, Data Structures, to find out how, and read R. Sedgewick, *Algorithms in C*, Addison-Wesley, 1990 (used in COS 226)**

Searching, cont'd

```
int count = 0;
struct node *root = NULL;

int lookup(char *name) {
    struct node *p = search(root, name);

    if (p == NULL) {
        p = insert(root, NULL, strsave(name));
        p->info = count++;
    }
    return p->info;
}

int main(int argc, char *argv[]) {
    int i;
    char buf[128];

    while (scanf("%s", buf) == 1)
        lookup(buf);
    for (i = 1; i < argc; i++) {
        int k = lookup(argv[i]);
        printf("%d\t%s\n", k, argv[i]);
    }
    print(root);
    return 0;
}
```

Printing Trees

- **Sorting is 'free:' Print the left subtree, print the key, print the right subtree**

```
void print(struct node *tree) {
    if (tree != NULL) {
        print(tree->left);
        printf("%d\t%s\n", tree->info, tree->key);
        print(tree->right);
    }
}
```

```
% lcc -I/u/cs126/include lookup2.c /u/cs126/lib/libmisc.a
% echo P R I N C E T O N | a.out
```

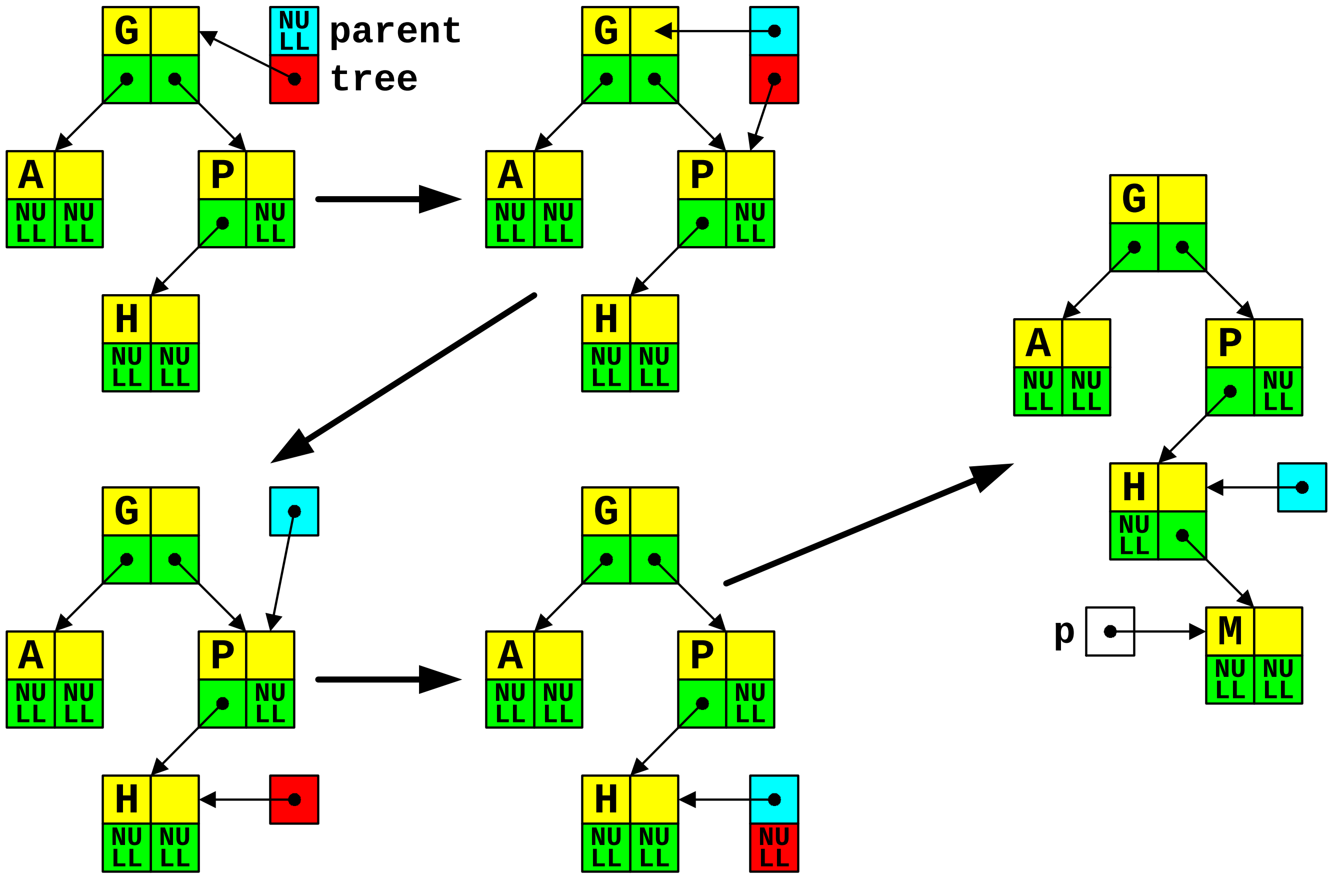
```
4   C
5   E
2   I
3   N
7   O
0   P
1   R
6   T
```

- **Ways to *traverse* trees; 'visit' means 'process the node,' e.g., print its key**

preorder:	***visit***	**traverse left**	**traverse right**
inorder:	**traverse left**	***visit***	**traverse right (alá `print`)**
postorder:	**traverse left**	**traverse right**	***visit***

Inserting in Binary Trees

- `insert` is like `search`, but it must remember ***parent nodes*** in order to set the `left` or `right` field



`insert` must also handle the ***empty tree***, which occurs when `parent` is `NULL`

Inserting in Binary Trees, cont'd

```
struct node *insert(struct node *tree, struct node *parent, char *q) {
    if (tree != NULL) {
        if (strcmp(q, tree->key) < 0)
            return insert(tree->left,  tree, q);
        else
            return insert(tree->right, tree, q);
    } else {
        struct node *p = emalloc(sizeof (struct node));
        p->key = q;
        p->left = p->right = NULL;
        if (parent == NULL)
            root = p;
        else if (strcmp(q, parent->key) < 0)
            parent->left = p;
        else
            parent->right = p;
        return p;
    }
}

int lookup(char *name) {
    struct node *p = search(root, name);

    if (p == NULL) {
        p = insert(root, NULL, strsave(name));
    …
}
```