Program Design

1. **Problem statement and *requirements*:**

   What is the problem?

2. ***Specification*:**

   Detailed description of ***what*** the system does instead of *how*.

3. ***Design*:**

   Explore design space (like “back of the envelope” calculations), identify algorithms and key ***interfaces***

4. ***Programming*:**

   Implement it in the ***simplest*** possible way; use libraries

5. ***Testing*:**

   Debug and test until the implementation is ***correct***

6. ***Iterate*:**

   Do the design and implementation ***conform*** to the ***specification***?

Stepwise Refinement

- Top-down design

  starts with a ***high-level abstract*** solution

  refines it repeatedly by successive transformations to lower-level solutions

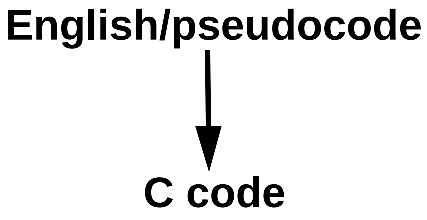
  refinement ends at programming language statements

- Key idea: each refinement or ***elaboration***

  must be ***small,*** **and** ***correct***

  must move toward final solution

- Accompany refinements with ***assertions*** to help ensure ***correctness***
- Refinements use English and pseudocode, but ultimately result in ***code***:



English/pseudocode

C code

Example: How Many Library Books are Never Used?

1. Problem statement:

The circulation file has a line of author& title for each checked out book.

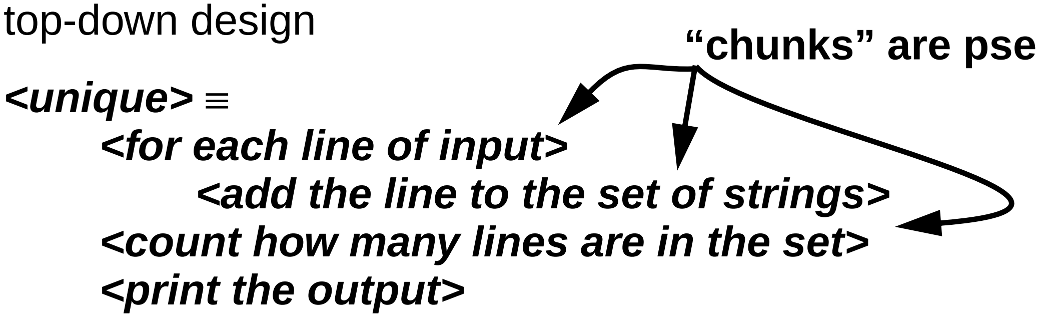
Need a program to answer how many books circulate in a year

2. Specification:

`unique` reads its standard input and prints the number of distinct (non-redundant) lines on the standard output

3. Design: how many unique lines are in a typical circulation file?

top-down design



“chunks” are pseudocode to be elaborated

```
<unique> ≡
    <for each line of input>
        <add the line to the set of strings>
    <count how many lines are in the set>
    <print the output>
```

4. Programming: make forward progress by elaborating chunks

```
<count how many lines in the set> ≡
    count = 0;
    <for each element of the set>
        count++;
```

What Modules?

- ADTs: sets of strings

- Modules:

main.c handle command-line arguments (if any) and top-level loops

```
<unique> ≡
    <includes>
    <defines>
    int main(int argc, char *argv[]) {
        <locals>
        <for each line of input>
            <add the line to the set of strings>
        <count how many lines are in the set>
        <print the output>
        return EXIT_SUCCESS;
}
```

strset.h interface for sets of strings

strset.c initial implementation of sets of strings

- **Use RCS to track changes**

main.c,v

strset.h,v

strset.c,v

Elaboration

- Do the easy chunks first

<print the output> ≡

```
    printf("%d\n", count);
```

<locals> ≡

```
    int count = 0;
```

<includes> ≡

```
    #include <stdio.h>
```

- Some elaborations can be done ***without*** defining the ADTs

<for each line in the input> ≡

```
    while (gets(line))
```

<defines> ≡

```
    #define MAXLINE 512
```

<locals> +≡ **indicates that code is *appended* to the chunk**

```
    char line[MAXLINE];
```

ADT: Sets of Strings

`strset.h` describes ***abstract*** operations, ***not*** implementation; ***what***, not ***how***

```
#ifndef STRSET_INCLUDED
#define STRSET_INCLUDED

#define T Strset_T
typedef struct T *T;

T Strset_new(void);       /* allocates and returns a new, empty set */

void Strset_free(T *set);
    /* deallocates *set and its contents, set *set to NULL */

void Strset_add(T set, char *str);
    /* adds str to set, if str is not already in set */

void Strset_delete(T set, char *str);
    /* removes str from set, if str is in set */

int Strset_member(T set, char *str);
    /* returns 1 if str is in set, else 0 */

void Strset_foreach(T set, void apply(char *str, void *cl), void *cl);
    /* executes apply(s, cl) for each string s in set */

/* It is a checked runtime error to pass a NULL T, *T, char*, or apply
to any function in this interface. */

#undef T
#endif
```

naming *convention*: ugly, but avoids name *collisions*

***opaque pointer* type; clients can't see innards**

"closure"

client *responsibilities*

Elaboration, cont’d

- ADT interface gives enough information to finish the client, **`main.c`**

<locals> +≡

```
    Strset_T set = Strset_new();
```

<includes> +≡

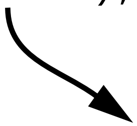
```
    #include "strset.h"
```

<add the line to the set of strings> ≡

```
    Strset_add(set, line);
```

<count how many lines are in the set > ≡

```
    Strset_foreach(set, cardinality, &count);
```



```
    static void cardinality(char *str, void *cl) {
        int *p = cl;

        (*p)++;     /* or (*(int *)cl)++; */
    }
```

- Implement clients of ADTs ***before*** the ADTs themselves; helps ***expose*** design ***inadequacies***

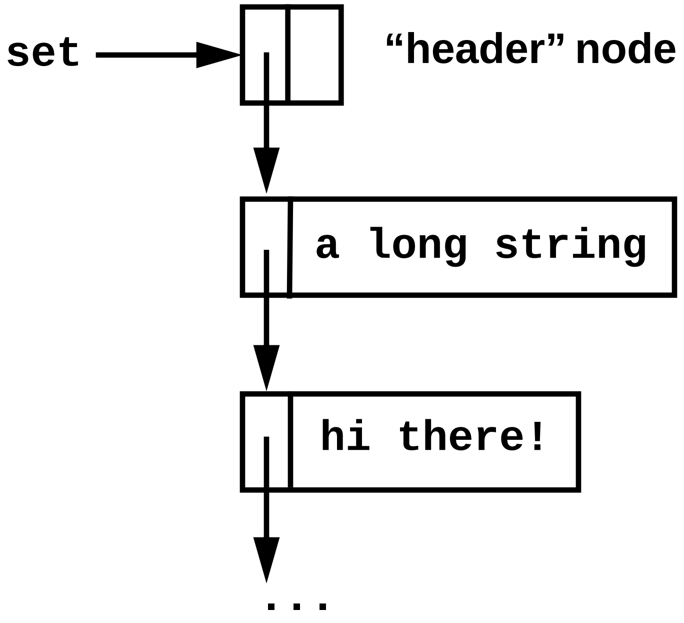
Strset

- Initial implementation can be ***simple***; it might suffice ...

- Implementation ***reveals*** the innards of the ***opaque*** type: a list of strings

```
#include "strset.h"
#define T Strset_T

struct T {
    T next;
    char str[1];
};
```



- **`Strset_new`** allocates a new header node

```
T Strset_new(void) {
    T set = calloc(1, sizeof *set);

    assert(set);
    return set;
}
```

OK during development and in COS 217, but not in production programs

Initial Implementation of Strset

- For now, implement only enough of the ADT to test **`unique`**

```
void Strset_add(T set, char *str) {
    T p = set;

    assert(set);
    assert(str);
    while ((p = p->next) != NULL)
        if (strcmp(str, p->str) == 0)
            return;
    p = malloc(sizeof *p + strlen(str));
    assert(p);
    strcpy(p->str, str);
    p->next = set->next;
    set->next = p;
}

void Strset_foreach(T set, void apply(char *str, void *cl),
void *cl) {
    assert(set);
    assert(apply);
    while ((set = set->next) != NULL)
        apply(set->str, cl);
}
```

Testing

5. Testing: `unique` works, but runs too slowly on *large* inputs; why?

improve **`strset`**'s implementation; don't change its interface

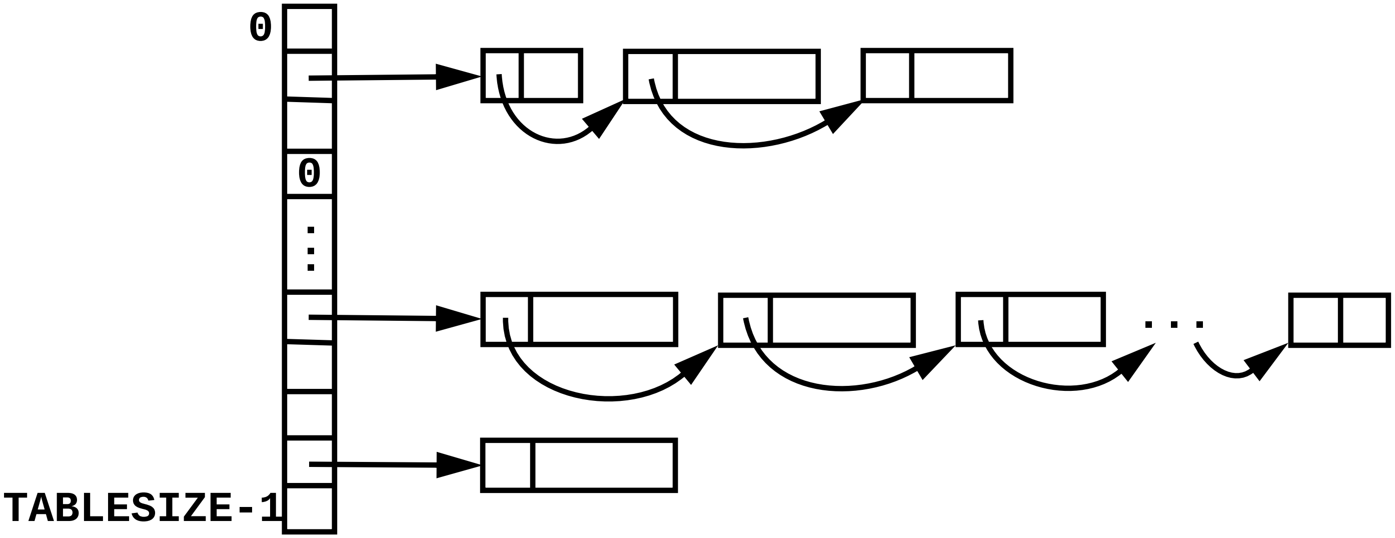
- Solution: use a ***hash table*** to represent a set of strings

  a set is a pointer to an array of **`TABLESIZE`** linked lists

  crunch the string into an integer **`h`**

  let **`i = h%TABLESIZE`**

  search the **`i`**th linked list for the string, or
  add the string to the head of the **`i`**th list



Better Implementation of Strset

```
#include <assert.h>
#include <stdlib.h>
#include <string.h>
#include "strset.h"
#define T Strset_T

#define TABLESIZE 97
struct T {
    struct elem {
        struct elem *next;
        char str[1];
    } *table[TABLESIZE];
};

void Strset_free(T *set) {
    int i;

    assert(set && *set);
    for (i = 0; i < TABLESIZE; i++) {
        struct elem *p, *q;
        for (p = (*set)->table[i]; p; p = q) {
            q = p->next;
            free(p);
        }
    }
    free(*set);
    *set = NULL;
}
```

same as above!

```
T Strset_new(void) {
    T set = calloc(1, sizeof *set);

    assert(set);
    return set;
}
```

Better Implementation of Strset, cont’d

```
static unsigned hash(char *str) {
    unsigned h = 0;

    while (*str)
        h = (h<<1) + *str++;
    return h;
}

void Strset_add(T set, char *str) {
    int i;
    struct elem *p;

    assert(set);
    assert(str);
    i = hash(str)%TABLESIZE;
    for (p = set->table[i]; p; p = p->next)
        if (strcmp(str, p->str) == 0)
            return;
    p = malloc(sizeof *p + strlen(str));
    assert(p);
    strcpy(p->str, str);
    p->next = set->table[i];
    set->table[i] = p;
}
```

Better Implementation of Strset, cont'd

```
void Strset_foreach(T set, void apply(char *str, void *cl),
void *cl) {
    int i;

    assert(set);
    assert(apply);
    for (i = 0; i < TABLESIZE; i++) {
        struct elem *p;
        for (p = set->table[i]; p; p = p->next)
            apply(p->str, cl);
    }
}
```

- see files in **`src/{strset,unique}`**; RCS files track ***all*** improvements

More Testing

- ***More*** testing

  test on “typical” inputs

  test on ***extreme*** inputs:

    a file with blank lines
    a very long file
    a long file with lines that are all identical
    a file with very long lines
    an empty file
    ...

- Very long lines causes **`unique`** to crash!

  <for each line in the input> ≡

```
    while (gets(line))
```

`gets` can’t check length of `line`

6. Iterate

go to step 2, amend the ***specification***:

  “Only the first 511 characters of a line are significant”

go to step 4 (programming) and fix the error (use RCS)

go to step 5 (testing) and repeat ***all*** of the tests

iterate again.