

Important: Before reading WORD\_COMPONENTS, please read or at least skim the program for GB\_WORDS.

**1. Components.** This simple demonstration program computes the connected components of the GraphBase graph of five-letter words. It prints the words in order of decreasing weight, showing the number of edges, components, and isolated vertices present in the graph defined by the first  $n$  words for all  $n$ .

```
#include "gb_graph.h"      /* the GraphBase data structures */
#include "gb_words.h"      /* the words routine */
{ Preprocessor definitions }
main()
{ Graph *g = words(0L, 0L, 0L, 0L);    /* the graph we love */
  Vertex *v;    /* the current vertex being added to the component structure */
  Arc *a;       /* the current arc of interest */
  long n = 0;   /* the number of vertices in the component structure */
  long isol = 0; /* the number of isolated vertices in the component structure */
  long comp = 0; /* the current number of components */
  long m = 0;   /* the current number of edges */
  printf("Component\u201aanalysis\u201aof\u201a%s\n", g->id);
  for (v = g->vertices; v < g->vertices + g->n; v++) {
    n++, printf("%4ld:\u201a%5ld\u201a%s", n, v->weight, v->name);
    { Add vertex v to the component structure, printing out any components it joins 2};
    printf(";\u201a;c=%ld,i=%ld,m=%ld\n", comp, isol, m);
  }
  { Display all unusual components 5};
  return 0; /* normal exit */
}
```

**2.** The arcs from  $v$  to previous vertices all appear on the list  $v\rightarrow\text{arcs}$  after the arcs from  $v$  to future vertices. In this program, we aren't interested in the future, only the past; so we skip the initial arcs.

```
{ Add vertex v to the component structure, printing out any components it joins 2} \equiv
{ Make v a component all by itself 3};
a = v\rightarrow\text{arcs};
while (a \wedge a\rightarrow\text{tip} > v) a = a\rightarrow\text{next};
if (\neg a) printf("[1]"); /* indicate that this word is isolated */
else { long c = 0; /* the number of merge steps performed because of v */
  for ( ; a; a = a\rightarrow\text{next}) { register Vertex *u = a\rightarrow\text{tip};
    m++;
    { Merge the components of u and v, if they differ 4};
  }
  printf("\u201a in \u201a %s [%ld] ", v\rightarrow\text{master}\rightarrow\text{name}, v\rightarrow\text{master}\rightarrow\text{size}); /* show final component */
}
```

This code is used in section 1.

**3.** We keep track of connected components by using circular lists, a procedure that is known to take average time  $O(n)$  on truly random graphs [Knuth and Schönhage, *Theoretical Computer Science* **6** (1978), 281–315].

Namely, if  $v$  is a vertex, all the vertices in its component will be in the list

$$v, \ v\text{-}link, \ v\text{-}link\text{-}link, \ \dots,$$

eventually returning to  $v$  again. There is also a master vertex in each component,  $v\text{-}master$ ; if  $v$  is the master vertex,  $v\text{-}size$  will be the number of vertices in its component.

```
#define link z.V /* link to next vertex in component (occupies utility field z) */
#define master y.V /* pointer to master vertex in component */
#define size x.I /* size of component, kept up to date for master vertices only */

⟨ Make v a component all by itself 3 ⟩ ≡
  v-link = v;
  v-master = v;
  v-size = 1;
  isol++;
  comp++;
```

This code is used in section 2.

**4.** When two components merge together, we change the identity of the master vertex in the smaller component. The master vertex representing  $v$  itself will change if  $v$  is adjacent to any prior vertex.

⟨ Merge the components of  $u$  and  $v$ , if they differ 4 ⟩ ≡

```
  u = u-master;
  if (u ≠ v-master) { register Vertex *w = v-master, *t;
    if (u-size < w-size) {
      if (c++ > 0) printf("%s\u2022%s[%ld]", (c ≡ 2 ? "\u2022with" : ","),
        u-name, u-size);
      w-size += u-size;
      if (u-size ≡ 1) isol--;
      for (t = u-link; t ≠ u; t = t-link) t-master = w;
      u-master = w;
    } else {
      if (c++ > 0) printf("%s\u2022%s[%ld]", (c ≡ 2 ? "\u2022with" : ","),
        w-name, w-size);
      if (u-size ≡ 1) isol--;
      u-size += w-size;
      if (w-size ≡ 1) isol--;
      for (t = w-link; t ≠ w; t = t-link) t-master = u;
      w-master = u;
    }
    t = u-link;
    u-link = w-link;
    w-link = t;
    comp--;
  }
```

This code is used in section 2.

5. The *words* graph has one giant component and lots of isolated vertices. We consider all other components unusual, so we print them out when the other computation is done.

```
< Display all unusual components 5 > ==
printf("\nThe\u201cfollowing\u201dnon-isolated\u201cwords\u201ddidn't\u201cjoin\u201dthe\u201cgiant\u201ccomponent:\n");
for (v = g->vertices; v < g->vertices + g->n; v++) {
    if (v->master == v & v->size > 1 & v->size + v->size < g->n) { register Vertex *u;
        long c = 1; /* count of number printed on current line */
        printf("%s", v->name);
        for (u = v->link; u != v; u = u->link) {
            if (c++ == 12) putchar('\n'), c = 1;
            printf(" \u201c%s", u->name);
        }
        putchar('\n');
    }
}
```

This code is used in section 1.

**6. Index.** We close with a list that shows where the identifiers of this program are defined and used.

*a:* 1.  
**Arc:** 1.  
*arcs:* 2.  
*c:* 2, 5.  
*comp:* 1, 3, 4.  
*g:* 1.  
**Graph:** 1.  
*id:* 1.  
*isol:* 1, 3, 4.  
Knuth, Donald Ervin: 3.  
*link:* 3, 4, 5.  
*m:* 1.  
*main:* 1.  
*master:* 2, 3, 4, 5.  
*n:* 1.  
*name:* 1, 2, 4, 5.  
*next:* 2.  
*printf:* 1, 2, 4, 5.  
*putchar:* 5.  
Schönhage, Arnold: 3.  
*size:* 2, 3, 4, 5.  
*t:* 4.  
*tip:* 2.  
*u:* 2, 5.  
*v:* 1.  
**Vertex:** 1, 2, 4, 5.  
*vertices:* 1, 5.  
*w:* 4.  
*weight:* 1.  
*words:* 1, 5.

- ⟨ Add vertex  $v$  to the component structure, printing out any components it joins 2⟩ Used in section 1.
- ⟨ Display all unusual components 5⟩ Used in section 1.
- ⟨ Make  $v$  a component all by itself 3⟩ Used in section 2.
- ⟨ Merge the components of  $u$  and  $v$ , if they differ 4⟩ Used in section 2.

## WORD\_COMPONENTS

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