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␣analysis␣of␣%s\n", g→id);
    for (v = g→vertices; v < g→vertices + g→n; v++) {
      n++, printf("%4ld:␣%5ld␣%s", n, v→weight, v→name);
      ⟨ Add vertex v to the component structure, printing out any components it joins 2 ⟩;
      printf(";␣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 $v\to arcs$ 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 ⟩ ≡
  ⟨ Make v a component all by itself 3 ⟩;
  a = v→arcs;
  while (a ∧ a→tip > v) a = a→next;
  if (¬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→next) { register Vertex *u = a→tip;
      m++;
      ⟨ Merge the components of u and v, if they differ 4 ⟩;
    }
    printf("␣in␣%s[%ld]", v→master→name, v→master→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

$$v,\ v\to link,\ v\to link\to link,\ \ldots,$$

eventually returning to v again. There is also a master vertex in each component, $v\to master$; if v is the master vertex, $v\to size$ 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␣%s[%ld]", (c ≡ 2 ? "␣with" : ","), 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␣%s[%ld]", (c ≡ 2 ? "␣with" : ","), 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␣following␣non-isolated␣words␣didn't␣join␣the␣giant␣component:\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("␣%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.

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