1*. Intro. Here's an implementation of the Panholzer–Prodinger algorithm, which generates a uniformly random "decorated" ternary tree. (It generalizes the binary method of Rémy, Algorithm 7.2.1.6R, and solves exercise 7.2.1.6–65.) They presented it in *Discrete Mathematics* **250** (2002), 181–195, but without spelling out an efficient implementation.

Although the algorithm is short, it is not easy to discover; the reader who thinks otherwise is invited to invent it before reading further.

I'm using a linked structure as in the presentation of in Rémy's method in Volume 4A: There are $3n+1$ links L_0, L_1, ..., L_{3n}, which are a permutation of the integers $\{0,1,\ldots,3n\}$. Internal (branch) nodes have numbers congruent to 2 (mod 3). The root is node number L_0; the descendants of branch $3k-1$ are the nodes numbered L_{3k-2}, L_{3k-1}, L_{3k}. For example, if $n=3$ and $(L_0,L_1,\ldots,L_9)=(5,0,1,3,2,6,7,8,4,9)$, the root is node 5 (a branch node); its left child is node 2 (another branch), its middle child is node 6 (external), and its right child is node 8 (yet another branch).

I also maintain the inverse permutation $(P_0,\ldots,P_{3n})$, so that we can determine the parent of each node.

```
#define nmax 1000
#include <stdio.h>
#include <stdlib.h>
#include "gb_flip.h"   /* random number generator from the Stanford GraphBase */
  int nn, seed;   /* command-line parameters */
  int L[nmax], P[nmax];   /* the links and their inverses */
  main(int argc, char *argv[])
  {
    register int i, j, k, n, nnn, p, q, r, x;
    ⟨Process the command line 2⟩;
    for (n = L[0] = P[0] = 0; n < nn; )
      ⟨Extend a solution for n to a solution for n + 1, and increase n 3⟩;
    ⟨Print the answer in 'quad' format 7*⟩;
  }
```

2. ⟨Process the command line 2⟩ ≡

```
  if (argc ≠ 3 ∨ sscanf(argv[1], "%d", &nn) ≠ 1 ∨ sscanf(argv[2], "%d", &seed) ≠ 1) {
    fprintf(stderr, "Usage:␣%s␣n␣seed\n", argv[0]);
    exit(−1);
  }
  gb_init_rand(seed);
```

This code is used in section 1*.

3. **#define** *sanity_checking* 1

⟨ Extend a solution for n to a solution for $n+1$, and increase n 3 ⟩ ≡

```
{
  n++;
  nnn = 3 * n;
  x = gb_unif_rand(3 * (nnn - 1) * (nnn - 2));
  p = nnn - (x % 3);
  q = nnn - ((x + 1) % 3);
  r = nnn - ((x + 2) % 3);
  k = ((int)(x/3)) % (nnn - 2);
  j = (int)(x/(9 * n - 6));
  L[p] = nnn, P[nnn] = p;
  L[q] = L[k], P[L[k]] = q, L[k] = nnn - 1, P[nnn - 1] = k;
  ⟨ Do the magic switcheroo 5 ⟩;
  if (sanity_checking) {
    for (i = 0; i ≤ nnn; i++)
      if (P[L[i]] ≠ i) {
        fprintf(stderr, "(whoa---the␣links␣are␣fouled␣up!)\n");
        exit(-2);
      }
  }
}
```

This code is used in section 1*.

4. Variables j and L_k correspond to P-and-P's nodes y and x; they are random integers with $0 \le j \le 3n+1$ and $0 \le k \le 3n$. The basic idea is to insert a new branch node (node number $3n-1$) in place of node L_k; but this new node has the old node L_k as one of its children (pointed to by L_q), so we haven't really lost anything. Another child, pointed to by L_p, is the leaf $3n$. The third child, pointed to by L_r, has to somehow encode the fact that we also need to place the leaf $3n-2$ while maintaining randomness.

There are two main cases, depending on whether node number y is a proper ancestor of node number x.

The crucial point, proved in the paper, is that we can recover x, y, and p by looking at the switched links.

5. ⟨ Do the magic switcheroo 5 ⟩ ≡

```
for (i = k + 1 - ((k + 2) % 3); i > 0 ∧ i ≠ j; i = P[i] + 1 - ((P[i] + 2) % 3)) ;
if (i > 0) ⟨ Do the harder case 6 ⟩
else {
  if (j ≡ L[q]) {      /* y = x */
    L[r] = L[q], P[L[q]] = r, L[q] = nnn - 2, P[nnn - 2] = q;
  } else if (j ≡ nnn - 2) {      /* y is the special leaf */
    L[r] = nnn - 2, P[nnn - 2] = r;
  } else L[P[j]] = nnn - 2, P[nnn - 2] = P[j], L[r] = j, P[j] = r;
}
```

This code is used in section 3.

6. The "harder case" isn't really hard for the computer; it's just harder for a human being to visualize.

⟨ Do the harder case 6 ⟩ ≡

```
{
  L[k] = nnn - 2, P[nnn - 2] = k;
  i = P[j];      /* the link to y */
  L[i] = nnn - 1, P[nnn - 1] = i, L[r] = j, P[j] = r;
}
```

This code is used in section 5.

7* This version outputs the tree in the format accepted as command-line arguments to the program SKEW-TERNARY-CALC-RAW (which see).

⟨ Print the answer in 'quad' format 7* ⟩ ≡

```
for (k = 1; k ≤ nn; k++) {
  printf("␣%c", '@' + k);
  for (j = −2; j ≤ 0; j++) i = L[3 ∗ k + j], printf("%c", (i + 1) % 3 ? '-' : '@' + (int)(i + 1)/3);
}
```

This code is used in section 1*.

8* Index.

The following sections were changed by the change file: 1, 7, 8.

RANDOM-TERNARY-QUADS