- Dynamic programming and memoization.
- Anatomy of Git.

  - Start with a list with an even number of non-negative integers.
  - Each player in turn takes either the left-most number or the rightmost.
  - Idea is to get the largest possible sum.
- Example: starting with (6, 12, 0, 8), you (as first player) should take the 8. Whatever the second player takes, you also get the 12, for a total of 20.
- Assuming your opponent plays perfectly (i.e., to get as much as possible), how can you maximize your sum?
- Can solve this with exhaustive game-tree search.


```
  int bestSum(int[] V) {
    int total, i, N = V.length;
    for (i = 0, total = 0; i < N; i += 1) total
+= V[i];
    return bestSum(V, 0, N-1, total);
  }

  /** The largest sum obtainable by the first
player in the choosing
   *  game on the list V[LEFT .. RIGHT], assuming
that TOTAL is the
   *  sum of all the elements in V[LEFT .. RIGHT].
*/
  int bestSum(int[] V, int left, int right, int
total) {
    if (left > right)
      return 0;
    else {
      int L = total - bestSum(V, left+1, right,
total-V[left]);
      int R = total - bestSum(V, left, right-1,
```


- Time cost is $C(0) = 1,\ C(N) = 2C(N-1)$; so $C(N) \in \Theta(2^N)$

termediate results many times.

- Solution: *memoize* the intermediate results. Here, we pass in an $N \times N$ array ($N =$ `V.length`) of memoized results, initialized to -1.

```
  int bestSum(int[] V, int left, int right, int
total, int[][] memo) {
    if (left > right)
      return 0;
    else if (memo[left][right] == -1) {
      int L = total - bestSum(V, left+1, right,
total-V[left], memo);
      int R = total - bestSum(V, left, right-1,
total-V[right], memo);
      memo[left][right] = Math.max(L, R);
    }
    return memo[left][right];
   }
  }
```

- Now the number of recursive calls to `bestSum` must be $O(N^2)$, for $N =$ the length of V, an

presentation of this idea—known as *dynamic programming*—is iterative:

```
int bestSum(int[] V) {
  int[][] memo = new int[V.length][V.length];
  int[][] total = new int[V.length][V.length];
  for (int i = 0; i < V.length; i += 1)
    memo[i][i] = total[i][i] = V[i];
  for (int k = 1; k < V.length; k += 1)
    for (int i = 0; i < V.length-k-1; i += 1)
{
      total[i][i+k] = V[i] + total[i+1][i+k];
      int L = total[i][i+k] - memo[i+1][i+k];
      int R = total[i][i+k] - memo[i][i+k-1];
      memo[i][i+k] = Math.max(L, R);
    }
  return memo[0][V.length-1];
}
```

- That is, we figure out ahead of time the order in which the memoized version will fill in `memo`, and write an explicit loop.

to save space?

that is a subsequence of each of two other strings.

- **Example:** Longest common subsequence of
  "sally␣sells␣sea␣shells␣by␣the␣seashore"
  and
  "sarah␣sold␣salt␣sellers␣at␣the␣salt␣mines"
  is
  "sa␣sl␣sa␣sells␣␣␣the␣sae" (length 23)
- Similarity testing, for example.
- Obvious recursive algorithm:

```
/** Length of longest common subsequence of
S0[0..k0-1]
 *  and S1[0..k1-1] (pseudo Java) */
static int lls(String S0, int k0, String S1,
int k1) {
  if (k0 == 0 || k1 == 0) return 0;
  if (S0[k0-1] == S1[k1-1]) return 1 + lls(S0,
k0-1, S1, k1-1);
```


- Exponential, but obviously memoizable.


```
/** Length of longest common subsequence of S0[0..k0-1]
 *  and S1[0..k1-1] (pseudo Java) */
static int lls(String S0, int k0, String S1, int k1)
{
  int[][] memo = new int[k0+1][k1+1];
  for (int[] row : memo) Arrays.fill(row, -1);
  return lls(S0, k0, S1, k1, memo);
}

private static int lls(String S0, int k0, String S1, int k1, int[][] memo) {
  if (k0 == 0 || k1 == 0) return 0;
  if (memo[k0][k1] == -1) {
    if (S0[k0-1] == S1[k1-1])
      memo[k0][k1] = 1 + lls(S0, k0-1, S1, k1-1, memo);
    else
      memo[k0][k1] = Math.max(lls(S0, k0-1, S1, k1,
memo),
                              lls(S0, k0, S1, k1-1,
memo));
  }
  return memo[k0][k1];
```

```
/** Length of longest common subsequence of S0[0..k0-1]
 *  and S1[0..k1-1] (pseudo Java) */
static int lls(String S0, int k0, String S1, int k1)
{
  int[][] memo = new int[k0+1][k1+1];
  for (int[] row : memo) Arrays.fill(row, -1);
  return lls(S0, k0, S1, k1, memo);
}

private static int lls(String S0, int k0, String S1, int k1, int[][] memo) {
  if (k0 == 0 || k1 == 0) return 0;
  if (memo[k0][k1] == -1) {
    if (S0[k0-1] == S1[k1-1])
      memo[k0][k1] = 1 + lls(S0, k0-1, S1, k1-1, memo);
    else
      memo[k0][k1] = Math.max(lls(S0, k0-1, S1, k1,
memo),
                              lls(S0, k0, S1, k1-1,
memo));
  }
  return memo[k0][k1];
```


$\Theta(k_0 \cdot k_1)$

- Git is a distributed version-control system, apparently the most popular of these currently.
- Conceptually, it stores snapshots (*versions*) of the files and directory structure of a project, keeping track of their relationships, authors, dates, and log messages.
- It is *distributed,* in that there can be many copies of a given repository, each supporting indepenent development, with machinery to transmit and reconcile versions between repositories.
- Its operation is extremely fast (as these things go).

the Linux community when the developer of their previous, propietary VCS (Bitkeeper) withdrew the free version.

- Initial implementation effort seems to have taken about 2–3 months, in time for the 2.6.12 Linux kernel release in June, 2005.
- As for the name, according to Wikipedia,

  > Torvalds has quipped about the name Git, which is British English slang meaning "unpleasant person". Torvalds said: "I'm an egotistical bastard, and I name all my projects after myself. First 'Linux', now 'git'." The man page describes Git as "the stupid content tracker."

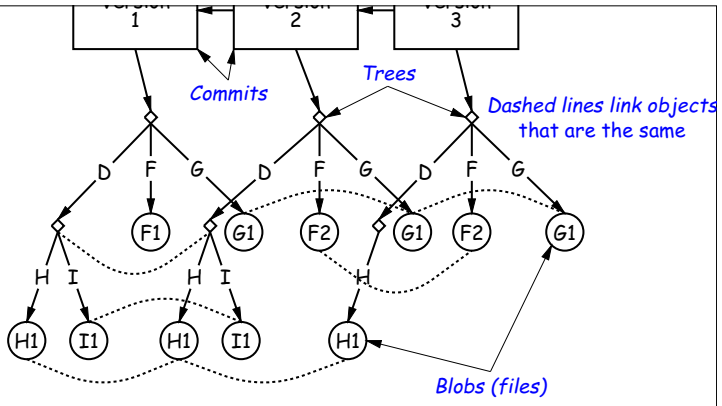
- Initially, was a collection of basic primitives (now called "plumbing") that could be scripted to provide desired functionality.

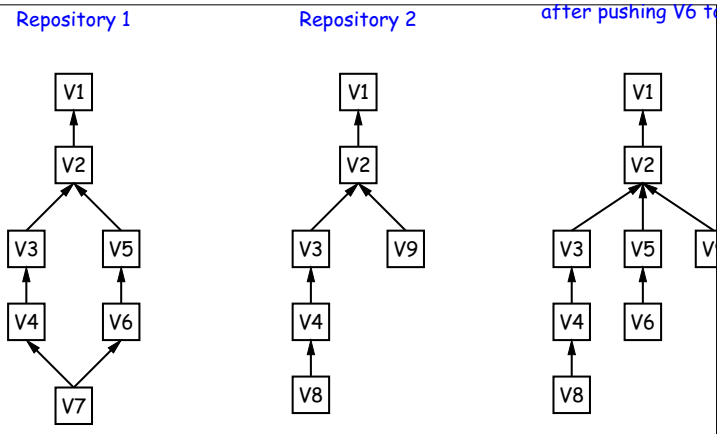
shots (called *commits*) of a complete project.

- The graph structure reflects ancestory: which versions came from which.
- Each commit contains
  - A directory tree of files (like a Unix directory).
  - Information about who committed and when.
  - Log message.
  - Pointers to commit (or commits, if there was a merge) from which the commit was derived.

of *object*:

- *Blobs:* basically hold contents of files.
- *Trees:* directory structures of files.
- *Commits:* Contain references to trees and additional information (committer, date, log message).
- *Tags:* References to commits or other objects, with additional information, intended to identify releases, other important versions, or various useful information. (Won't mention further today).





tities it to all versions.

- Repositories can transmit collections of versions to each other.
- Transmitting a commit from repository A to repository B requires only the transmission of those objects (files or directory trees) that B does not yet have (allowing speedy updating of repositories).
- Repositories maintain named *branches*, which are simply identifiers of particular commits that are updated to keep track of the most recent commits in various lines of development.
- Likewise, *tags* are essentially named pointers to particular commits. Differ from branches in that they are not usually changed.

tory.

- Repository may either be *bare* (just a collection of objects and metadata), or may be included as part of a working directory.
- The data of the repository is stored in various *objects* corresponding to files (or other "leaf" content), trees, and commits.
- To save space, data in files is *compressed*.
- Git can *garbage-collect* the objects from time to time to save additional space.

resent pointers between them?

- Want to be able to *transmit* objects from one repository to another with different contents. How do you transmit the pointers?
- Only want to transfer those objects that are missing in the target repository. How do we know which those are?
- Could use a counter in each repository to give each object there a unique name. But how can that work consistently for two independent repositories?

is universal.

- We use the names, then, as pointers.
- Solves the "Which objects don't you have?" problem in an obvious way.
- Conceptually, what is invariant about an object, regardless of repository, is its *contents*.
- But can't use the contents as the name for obvious reasons.
- Idea: Use a *hash of the contents* as the address.
- Problem: That doesn't work!
- Brilliant Idea: Use it anyway!!

unlikely to have a collision that we can ignore that possibility.

- *Cryptographic Hash Functions* have relevant property.
- Such a function, f, is designed to withstand cryptoanalytic attacks. In particular, should have
  - *Pre-image resistance:* given $h = f(m)$, should be computationally infeasible to find such a message m.
  - *Second pre-image resistance:* given message m_1, should be infeasible to find $m_2 \neq m_1$ such that $f(m_1) = f(m_2)$.
  - *Collision resistance:* should be difficult to find *any* two messages $m_1 \neq m_2$ such that $f(m_1) = f(m_2)$.
- With these properties, scheme of using hash

- Can play around with this using the `hashlib` module in Python3.
- All object names in Git are therefore 160-bit hash codes of contents, in hex.
- E.g. a recent commit in the shared CS61B repository could be fetched (if needed) with

```
git checkout e59849201956766218a3ad6ee1c3aab37dfec3fe
```