Concurrency in Go

"Don't communicate by sharing memory; instead, share memory by communicating"

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Cardinal Peak

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```
f088913 2
    /Users/mholiday/Dropbox/Emergency/FEMA_P-320_2014_508.pdf
    /Users/mholiday/Dropbox/Emergency/nps61-072915-01.pdf
```

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I want to find duplicate files based on their **content**

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    /Users/mholiday/Dropbox/Emergency/FEMA_P-320_2014_508.pdf
    /Users/mholiday/Dropbox/Emergency/nps61-072915-01.pdf
```

It takes nearly **5 minutes** to comb through my Dropbox folder

Sequential Approach

How it works: Declarations

```
package main

import (
    "crypto/md5"
    "fmt"
    "io"
    "log"
    "os"
    "path/filepath"
)

type pair struct {
    hash string
    path string
}

type fileList []string
type results  map[string]fileList
```

How it works: Hashing

```
func hashFile(path string) pair {
    file, err := os.Open(path)

    if err != nil && err != os.ErrNotExist {
        log.Fatal(err)
    }

    defer file.Close()

    hash := md5.New() // fast & good enough

    if _, err := io.Copy(hash, file); err != nil {
        log.Fatal(err)
    }

    // make a string so we can use it as a map key

    return pair{fmt.Sprintf("%x", hash.Sum(nil)), path}
}
```

How it works: Searching

```
func searchTree(dir string) (results, error) {
    hashes := make(results)

    err := filepath.Walk(dir, func(p string, fi os.FileInfo,
                                   err error) error {

        // ignore the error parm for now

        if fi.Mode().IsRegular() && fi.Size() > 0 {
            h := hashFile(p)
            hashes[h.hash] = append(hashes[h.hash], h.path)
        }

        return nil
    })

    return hashes, err
}
```

How it works: Output

```
func main() {
    if len(os.Args) < 2 {
        log.Fatal("Missing parameter, provide dir name!")
    }

    if hashes, err := searchTree(os.Args[1]); err == nil {
        for hash, files := range hashes {
            if (len(files) > 1) {
                // we will use just 7 chars like git

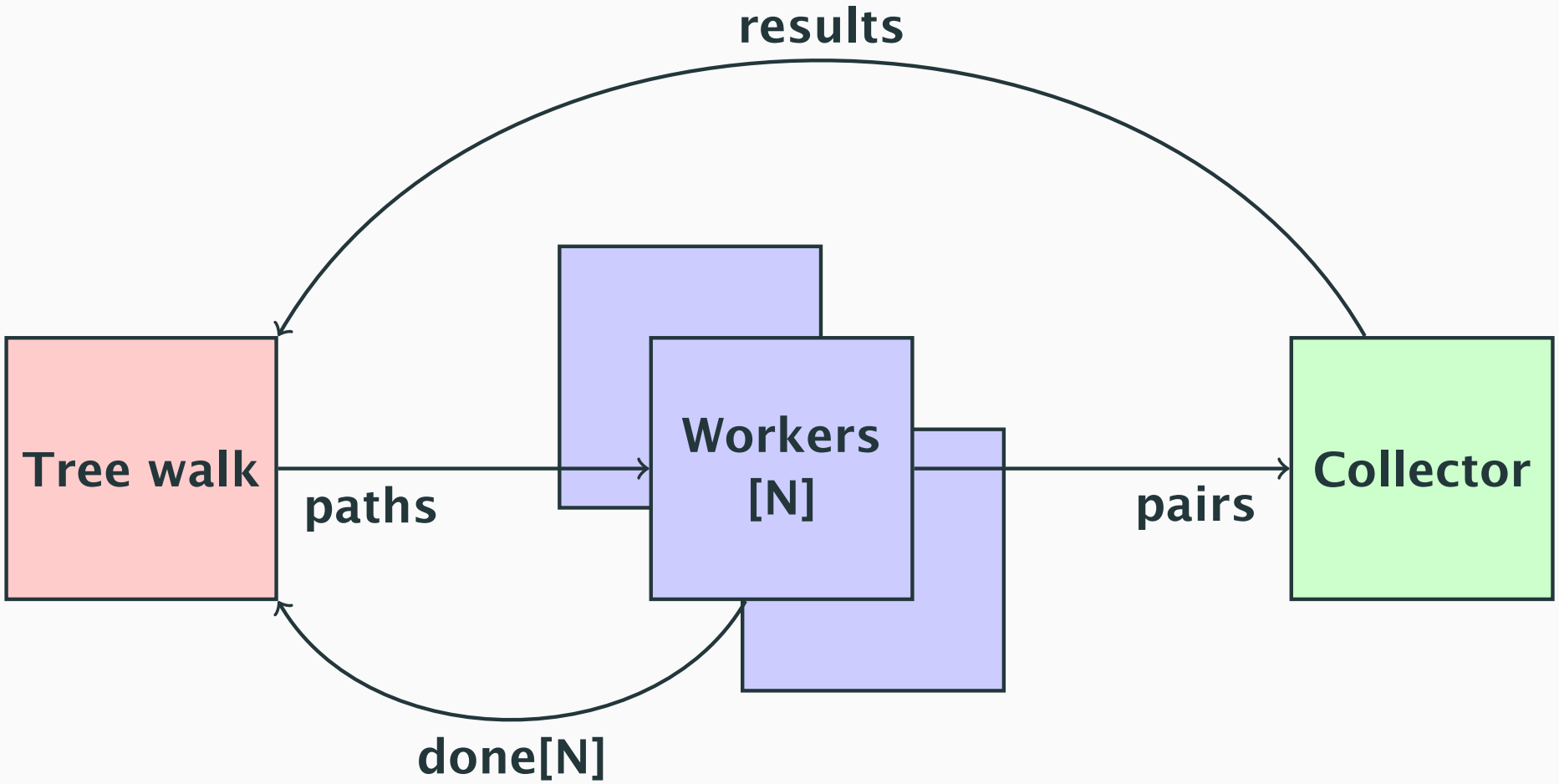
                fmt.Println(hash[:7], len(files))

                for _, file := range files {
                    fmt.Println("   ", file)
                }
            }
        }
    }
}
```

Concurrent Approach #1

A concurrent approach (like map-reduce)

Use a fixed pool of goroutines and a collector and channels



How it works: Collecting the hashes

```
func collectHashes(pairs <-chan pair, result chan<- results) {
    hashes := make(results)

    for p := range pairs {
        hashes[p.hash] = append(hashes[p.hash], p.path)
    }

    result <- hashes
}
```

How it works: Replacing the processor

```
func processFiles(paths <-chan string, pairs chan<- pair,
                  done chan<- bool) {
    for path := range paths {
        pairs <- hashFile(path)
    }

    done <- true
}
```

How it works: Replacing the tree walk

```
workers := 2 * runtime.GOMAXPROCS(0)

paths := make(chan string)
pairs := make(chan pair)
done := make(chan bool)
result := make(chan results)

for i := 0; i < workers; i++ {
    go processFiles(paths, pairs, done)
}

// we need another goroutine so we don't block here

go collectHashes(pairs, result)

. . .
```

How it works: Replacing the tree walk

```
err := filepath.Walk(dir, func(p string, fi os.FileInfo,
                                err error) error {
    // again, ignore the error passed in

    if fi.Mode().IsRegular() && fi.Size() > 0 {
        paths <- p
    }

    return nil
})

if err != nil {
    log.Fatal(err)
}

// we must close the paths channel so the workers stop
close(paths)
. . .
```

How it works: Replacing the tree walk

```
. . .

// wait for all the workers to be done

for i := 0; i < workers; i++ {
    <-done
}

// by closing pairs we signal that all the hashes
// have been collected; we have to do it here AFTER
// all the workers are done

close(pairs)

hashes := <-result

return hashes
```

Evaluation #1

56.11s in the version shown above

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48.75 with twice as many workers

How it works: Parallel tree walk

```
. . .

wg := new(sync.WaitGroup)

// multi-threaded walk of the directory tree; we need a
// waitGroup because we don't know how many to wait for

wg.Add(1)
err := walkDir(dir, paths, wg)

if err != nil {
    log.Fatal(err)
}

wg.Wait()
close(paths)

. . .
```

How it works: Parallel tree walk

```
func walkDir(dir string, paths chan<- string,
             wg *sync.WaitGroup) error {
    defer wg.Done()

    visit := func(p string, fi os.FileInfo, err error) error {
        // ignore the error passed in

        // ignore dir itself to avoid an infinite loop!
        if fi.Mode().IsDir() && p != dir {
            wg.Add(1)
            go walkDir(p, paths)
            return filepath.SkipDir
        }

        . . .
```

How it works: Parallel tree walk

```
        . . .

        if fi.Mode().IsRegular() && fi.Size() > 0 {
            paths <- p
        }

        return nil
    }

    return filepath.Walk(dir, visit)
}
```

Concurrent Approach #3

The final approach: Goroutines galore!

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Adding more workers actually makes the time grow longer

Channels as counting semaphores

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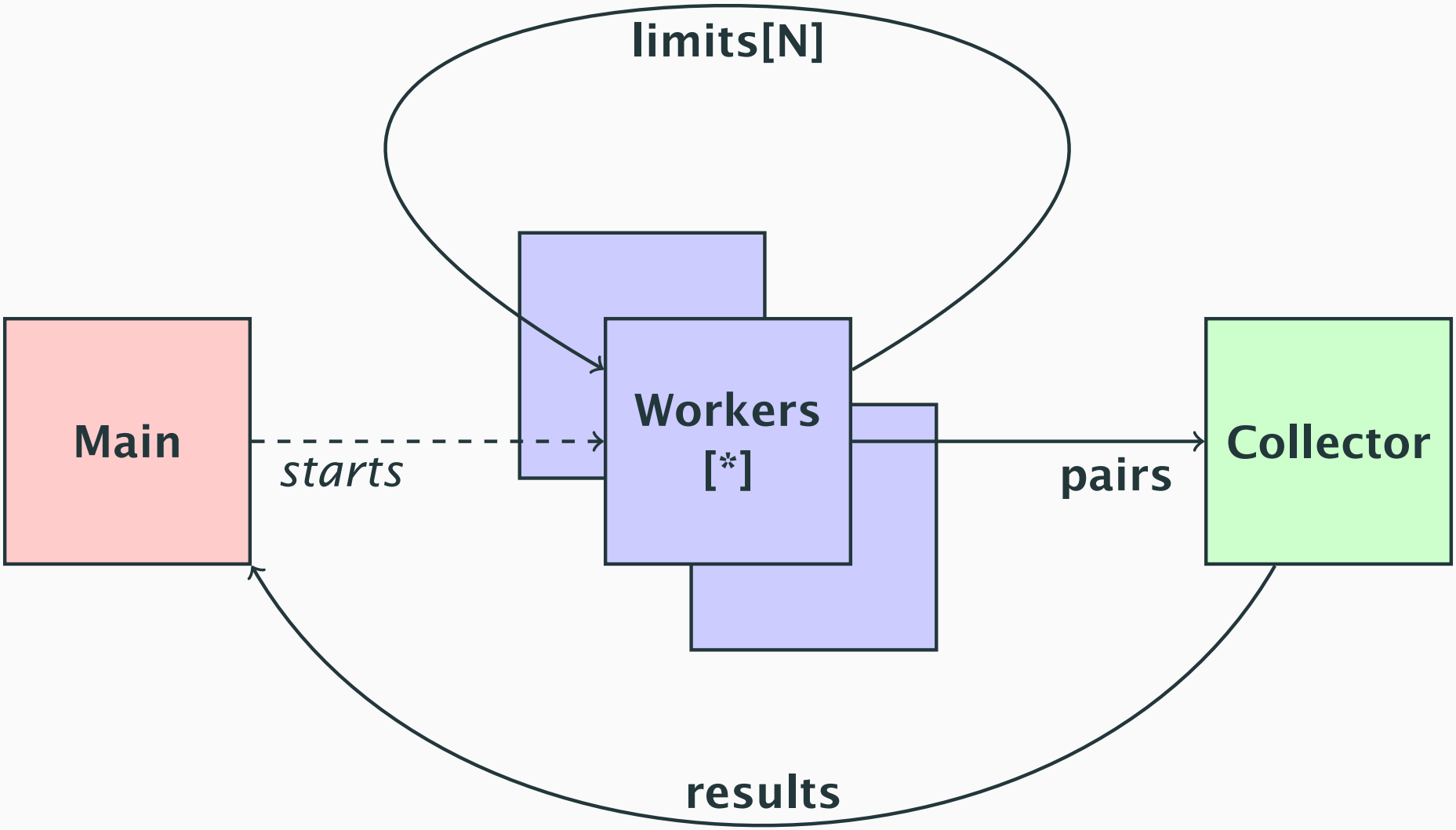
One goroutine can start for each one that quits

What that looks like



How it works: Limiting goroutines

```
// we don't need a channel for paths or to signal done but
// we need a buffered channel to act as a counting semaphore

wg := new(sync.WaitGroup)
limits := make(chan bool, workers)
pairs := make(chan pair, workers)
result := make(chan results)

go collect(pairs, result)

. . .
```

How it works: Limiting goroutines

```
. . .

wg.Add(1)
err := walkDir(dir, pairs, wg, limits)

if err != nil {
    log.Fatal(err)
}

wg.Wait()
close(pairs)

hashes := <-result

return hashes
```

How it works: Modified processing

```
func processFile(path string, pairs chan<- pair,
                 wg *sync.WaitGroup, limits chan bool) {
    defer wg.Done()

    limits <- true

    defer func() {
        <-limits
    }()

    pairs <- hashFile(path)
}
```

How it works: Modified tree walk

```
func walkDir(dir string, pairs chan<- pair, wg *sync.WaitGroup,
             limits chan bool) error {
    defer wg.Done()

    visit := func(p string, fi os.FileInfo, err error) error {
        // ignore the error passed in

        if fi.Mode().IsDir() && p != dir {
            wg.Add(1)
            go walkDir(p, pairs, wg, limits)
            return filepath.SkipDir
        }

        . . .
```

How it works: Modified tree walk

```
        . . .

        if fi.Mode().IsRegular() && fi.Size() > 0 {
            wg.Add(1)
            go processFile(p, pairs, wg, limits)
        }

        return nil
    }

    limits <- true

    defer func() {
        <-limits
    }()

    return filepath.Walk(dir, visit)
}
```

Comparing Directories (extra)

Merkle trees: nodes with hashes

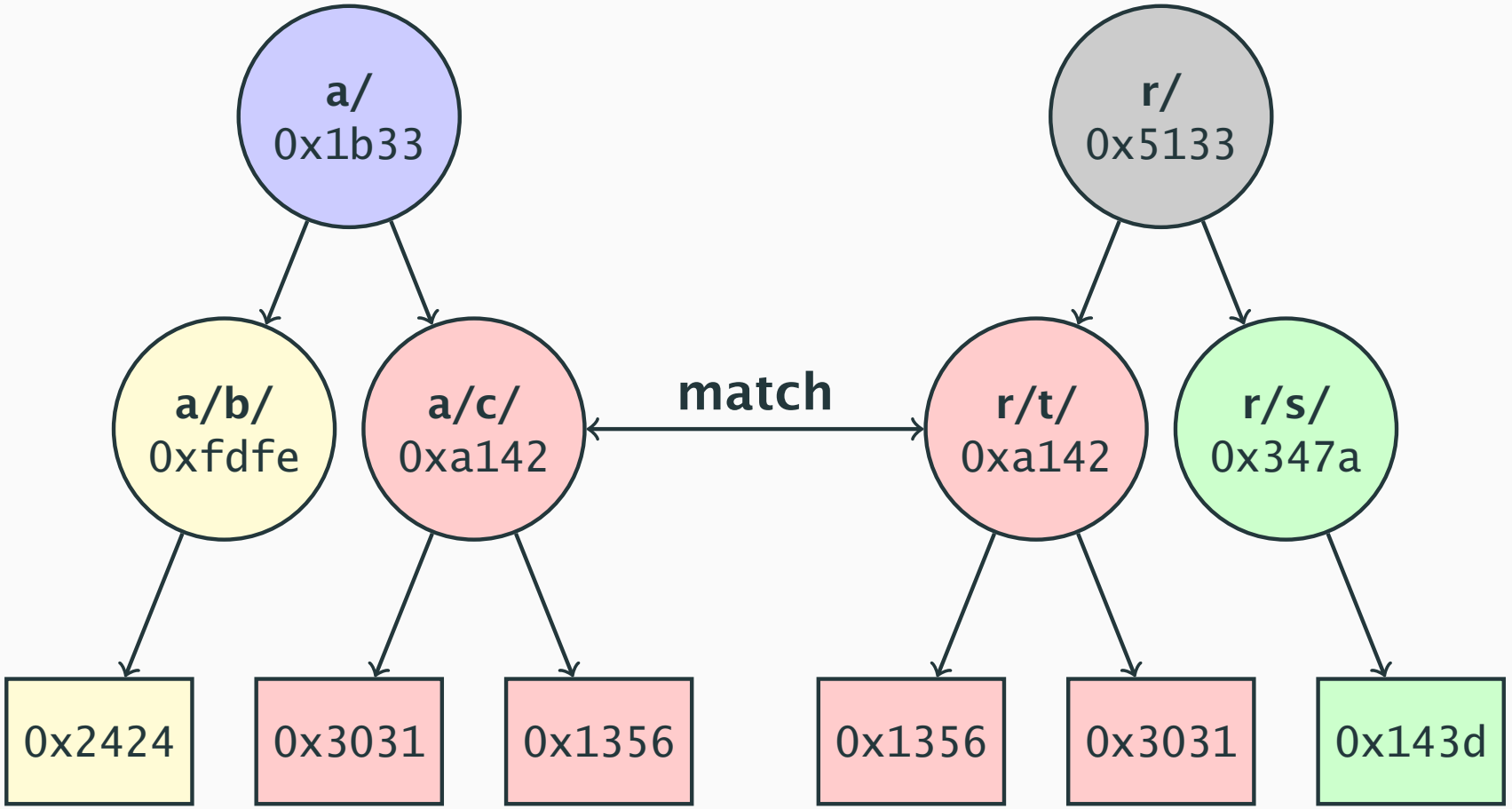
I'd like to identify entire directories that are identical to other directories (i.e., they have the same files, based on content, not name or mod date)

I can do that by building up a **Merkle tree**, which is a tree where each node has a hash based on its children

I'll calculate the hashes of files, and then calculate a hash over the collected hashes of a directory to get the hash for that directory as a whole

Merkle trees

Subtrees with the same hash are equal



How it works: Tree declarations

```
// one directory in the directory Merkle tree
type node struct {
    path  string
    hash  hash.Hash
    files []string
    child map[string]*node
}

// make a node to represent a directory in the tree
func makeNode(p string) *node {
    return &node{
        path:  p,
        hash:  md5.New(),
        child: make(map[string]*node)
    }
}
```

How it works: Modified collector

```
func collect(dir string, pairs <-chan pair,
             result chan<- results) {
    hashes := make(results)
    tree := makeNode(dir)

    for p := range pairs {
        hashes[p.hash] = append(hashes[p.hash], p.path)

        // insert this file hash into a merkle tree
        // using a path relative to the current dir

        rel, _ := filepath.Rel(dir, p.path)
        tree.insert(rel, p.hash)
    }

    tree.walk(hashes)  // and then calculate merkle hashes
    result <- hashes
}
```

How it works: Inserting

```
// insert a file's hash into the tree at the right spot
func (n *node) insert(path string, hash string) {
    s := strings.Split(path, "/")

    if len(s) == 1 {
        // we have a file in this directory
        n.files = append(n.files, hash)
    } else {
        // we may need to create the child on insert
        c := s[0]

        if n.child[c] == nil {
            n.child[c] = makeNode(filepath.Join(n.path, c))
        }

        n.child[c].insert(filepath.Join(s[1:]...), hash)
    }
}
```

How it works: Postorder traversal

```
// postorder walk to get a hash for each directory
func (n *node) walk(hashes results) string {
    for _, c := range n.child {
        n.files = append(n.files, c.walk(hashes))
    }

    // we need a consistent order to the hashes
    sort.Strings(n.files)

    for _, h := range n.files {
        n.hash.Write([]byte(h))
    }

    hash := fmt.Sprintf("%x", n.hash.Sum(nil))

    hashes[hash] = append(hashes[hash], n.path+"/")
    return hash
}
```

Some Gotchas

Gotchas 1: Deadlock

A goroutine is **preemptible** only when it starts a (non-inlined) function call, blocks on a channel or mutex, or makes a blocking system call.

Potential Problems

If your goroutine isn't preemptible, garbage collection will never run, because it must first "stop the world."

However, if the `main()` function exits, all goroutines terminate.

Gotchas 1: Deadlock example

```
go func() {
    var i byte

    for i = 0; i <= 255; i++ {
        // infinite loop does nothing
        // doesn't get elided
        // and can't be preempted
    }
}()

runtime.Gosched()    // yield execution
runtime.GC()         // force GC

// DEADLOCK

fmt.Println("Done")  // never happens
```

Gotchas 1: Deadlock fixed

```
go func() {
    var i byte

    for i = 0; i <= 255; i++ {
        // infinite loop does nothing
        // doesn't get elided

        // but we can yield
        if (i == 123) {
            runtime.Gosched()
        }
    }
}()

runtime.Gosched()    // yield execution
runtime.GC()         // force GC
fmt.Println("Done")  // prints Done
```

Gotchas 2: Closure capture

A closure shouldn't capture a **mutating** variable, e.g. a loop index.

If it does, it will get the wrong value!

```
for i := 0; i < 10; i++ {    // WRONG
    go func() {
        fmt.Println(i)
    }()
}
```

Instead, pass the variable's value as a parameter.

```
for i := 0; i < 10; i++ {  // RIGHT
    go func(i int) {
        fmt.Println(i)
    }(i)
}
```

Channel state reference

State	Receive	Send	Close
Nil	Block*	Block*	Panic
Empty	Block	Write	Close
Partly Full	Read	Write	Readable until empty
Full	Read	Block	
Closed	Default Value**	Panic	
Receive-only	OK	Compile Error	
Send-only	Compile Error	OK	

* `select` ignores a nil channel since it would always block

** Reading a closed channel returns `(<default-value>, !ok)`