RPCs in Go

Feb 15/16th, 2024

Outline

RPC Overview

Example: Writing an RPC server in Go

MapReduce: fault tolerance and optimizations

RPC Overview

Remote Procedure Call (RPC)

- Execute a procedure on a remote process (e.g on another server) as if it was local

- Request-response interface
    - Request: arguments to remote procedure
    - Response: return values of remote procedure

- Examples: client-server, master-worker, peer-peer communication

Example: Master-Worker

```
Master {
  func LaunchTasks() {
    for worker in workers {
      // want to call Worker.RunTask(...)
    }
  }
}
```

```
Worker {
  func RunTask(index) result {
    // ...
  }
}
```

Example: Master-Worker

```
Master {
  func LaunchTasks() {
    for worker in workers {
      index = worker.Index
      address = worker.Address
      request = MakeRequest(index)
      response = sendRPC("RunTask", address, request)
      result = response.Result
      handleResult(result)
    }
  }
}
```

```
Worker {
  func RunTask(index) result {
    // ...
  }
}
```

What is the problem?
How is performance?

Asynchronous RPC

Key Idea: Await RPC response in a separate thread

Multiple ways to implement this:

1. Pass a *callback* to RPC that will be invoked later

Asynchronous RPC

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1. Pass a *callback* to RPC that will be invoked later

```
func handleResponse {
    …
// e.g process result and notify the master
}

sendRPC("RunTask", address, request, handleResponse)
```

Asynchronous RPC

Key Idea: Await RPC response in a separate thread

Multiple ways to implement this:

1. Pass a *callback* to RPC that will be invoked later
2. Use *channels* to communicate RPC reply back to main thread

Asynchronous RPC

Key Idea: Await RPC response in a separate thread

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1. Pass a *callback* to RPC that will be invoked later
2. Use *channels* to communicate RPC reply back to main thread

```
for _, worker := range workers {
      go func() {
        channel <- sendRPC("RunTask", address, request)
      }()
}
select {
      case res := <-channel:
            handleResponse(res)
      default:
            // do other stuff
}
```

What's an example application where we would want asynchronous RPCs?

Writing a RPC server in GO

RPC Implementations in Go

- There are 3 types of RPC implementations in Go’s built-in library
    - net/rpc
    - net/rpc/jsonrpc
    - gRPC

RPCs in GO (net/rpc server)

- Write stub receiver methods in the form:

```
func (t *T) MethodName(args T1, reply *T2) error
```

- Create a server
  - Create a TCP server (or some other types of server to receive data)
  - Create a listener that will handle RPCs
  - Register the listener and accept inbound RPC
- See https://golang.org/pkg/net/rpc/ for more details

Go example: Word count server

```
type WordCountServer struct {
    addr string
}

type WordCountRequest struct {
    Input string
}

type WordCountReply struct {
    Counts map[string]int
}
```

```
func (*WordCountServer) Compute(
        request WordCountRequest,
        reply *WordCountReply) error {
    counts := make(map[string]int)
    input := request.Input
    tokens := strings.Fields(input)
    for _, t := range tokens {
        counts[t] += 1
    }
    reply.Counts = counts
    return nil
}
```

Step 1: write the stub function

Go example: Word count server

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type WordCountServer struct {
    addr string
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func (*WordCountServer) Compute(
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    counts := make(map[string]int)
    input := request.Input
    tokens := strings.Fields(input)
    for _, t := range tokens {
        counts[t] += 1
    }
    reply.Counts = counts
    return nil
}
```

Step 1: write the stub function

Go example: Word count server

```
func (server *WordCountServer) Listen() {
    rpc.Register(server)
    listener, err := net.Listen("tcp", server.addr)
    checkError(err)
    go func() {
        rpc.Accept(listener)
    }()
}
```

Step 2.1: create a server

Go example: Word count server

```
func (server *WordCountServer) Listen() {
	rpc.Register(server)
	listener, err := net.Listen("tcp", server.addr)
	checkError(err)
	go func() {
		rpc.Accept(listener)
	}()
}
```

Step 2.2: create a listener that handles RPCs

Go example: Word count server

```
func (server *WordCountServer) Listen() {
	rpc.Register(server)
	listener, err := net.Listen("tcp", server.addr)
	checkError(err)
	go func() {
		rpc.Accept(listener)
	}()
}
```

Step 2.3: register the listener and accept inbound RPCs

RPCs in GO (net/rpc client)

- Create a client
- Issue a RPC call
- Unpack return value

Go example: Word count client

```
func makeRequest(input string, serverAddr string) (map[string]int, error) {
	client, err := rpc.Dial("tcp", serverAddr)
	checkError(err)
	args := WordCountRequest{input}
	reply := WordCountReply{make(map[string]int)}
	err = client.Call("WordCountServer.Compute", args, &reply)
	if err != nil {
		return nil, err
	}
	return reply.Counts, nil
}
```

Step 1: create a client

Go example: Word count client

```
func makeRequest(input string, serverAddr string) (map[string]int, error) {
    client, err := rpc.Dial("tcp", serverAddr)
    checkError(err)
    args := WordCountRequest{input}
    reply := WordCountReply{make(map[string]int)}
    err = client.Call("WordCountServer.Compute", args, &reply)
    if err != nil {
        return nil, err
    }
    return reply.Counts, nil
}
```

Step 2.1: create the RPC arguments

Go example: Word count client

```go
func makeRequest(input string, serverAddr string) (map[string]int, error) {
	client, err := rpc.Dial("tcp", serverAddr)
	checkError(err)
	args := WordCountRequest{input}
	reply := WordCountReply{make(map[string]int)}
	err = client.Call("WordCountServer.Compute", args, &reply)
	if err != nil {
		return nil, err
	}
	return reply.Counts, nil
}
```

Step 2.2: Make a RPC call

Go example: Word count client-server

```go
func main() {
	serverAddr := "localhost:8888"
	server := WordCountServer{serverAddr}
	server.Listen()
	input1 := "hello I am good hello bye bye bye bye good night hello"
	wordcount, err := makeRequest(input1, serverAddr)
	checkError(err)
	fmt.Printf("Result: %v\n", wordcount)
}
```

Step 3: Unpack return values

```
Result: map[hello:3 I:1 am:1 good:2 bye:4 night:1]
```

Is this synchronous or asynchronous?

```
func makeRequest(input string, serverAddr string) (map[string]int, error) {
	client, err := rpc.Dial("tcp", serverAddr)
	checkError(err)
	args := WordCountRequest{input}
	reply := WordCountReply{make(map[string]int)}
	err = client.Call("WordCountServer.Compute", args, &reply)
	if err != nil {
		return nil, err
	}
	return reply.Counts, nil
}
```

Making client asynchronous - Option 1

```
func makeRequest(input string, serverAddr string) chan Result {
    client, err := rpc.Dial("tcp", serverAddr)
    checkError(err)
    args := WordCountRequest{input}
    reply := WordCountReply{make(map[string]int)}
    ch := make(chan Result)
    go func() {
        err := client.Call("WordCountServer.Compute", args, &reply)
        if err != nil {
            ch <- Result{nil, err} // something went wrong
        } else {
            ch <- Result{reply.Counts, nil} // success
        }
    }()
    return ch
}
```

Making client asynchronous - Option 2

```
func makeRequest(input string, serverAddr string) *Call {
	client, err := rpc.Dial("tcp", serverAddr)
	checkError(err)
	args := WordCountRequest{input}
	reply := WordCountReply{make(map[string]int)}
	return client.Go("WordCountServer.Compute", args, &reply, nil)
}
```

```
call := makeRequest(...)
<-call.Done
checkError(call.Error)
handleReply(call.Reply)
```

Go's net/rpc is at-most-once

- Opens a TCP connection and writes the request
  - TCP may retransmit but server's TCP receiver will **filter out duplicates internally**, with sequence numbers
  - No retry in Go RPC code (i.e will **not** create a second TCP connection)

- However, Go RPC returns an error if it doesn't get a reply
  - Perhaps after a TCP timeout
  - Perhaps server didn't see the request
  - Perhaps server processed request but server or network failed before reply came back

RPC and Assignment 1 and 2

- Go's RPC **isn't enough** for Assignments 1 and 2
  - It only applies to a single RPC call
  - If worker doesn't respond, master **re-sends** to another (e.g handling worker failures in part D of assignment 1-3)
    - Go RPC **can't detect** this kind of duplicate
  - **Breaks at-most-once semantics**
    - No problem in Assignments 1 and 2 (handles at application level)

- In Assignment 3, **you** will explicitly detect duplicates using techniques we've talked about in lectures

Exercise: Cristian’s algorithm

Implement a `CristianServer` that other machines sync their local time to

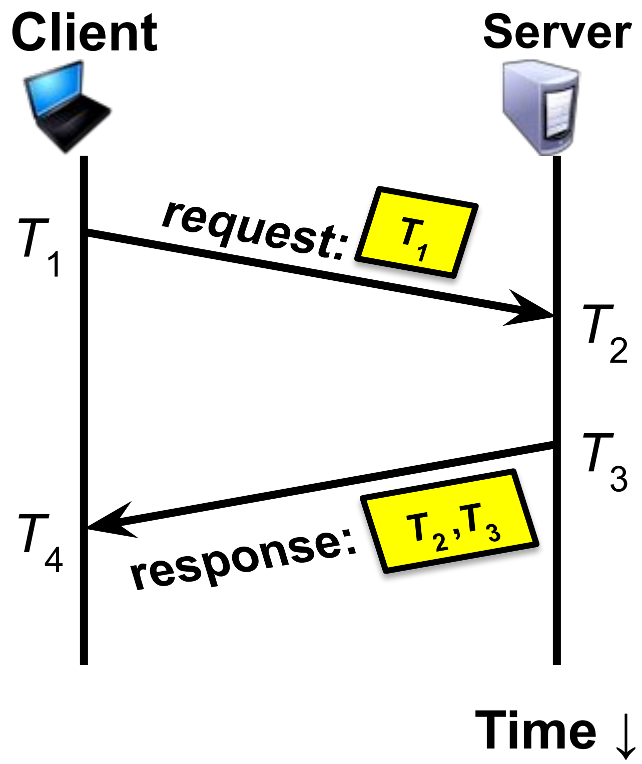
Cristian's algorithm: Outline

1. Client sends a ***request*** packet, timestamped with its local clock T_1

2. Server timestamps its receipt of the request T_2 with its local clock

3. Server sends a ***response*** packet with its local clock T_3 and T_2

4. Client locally timestamps its receipt of the server's response T_4



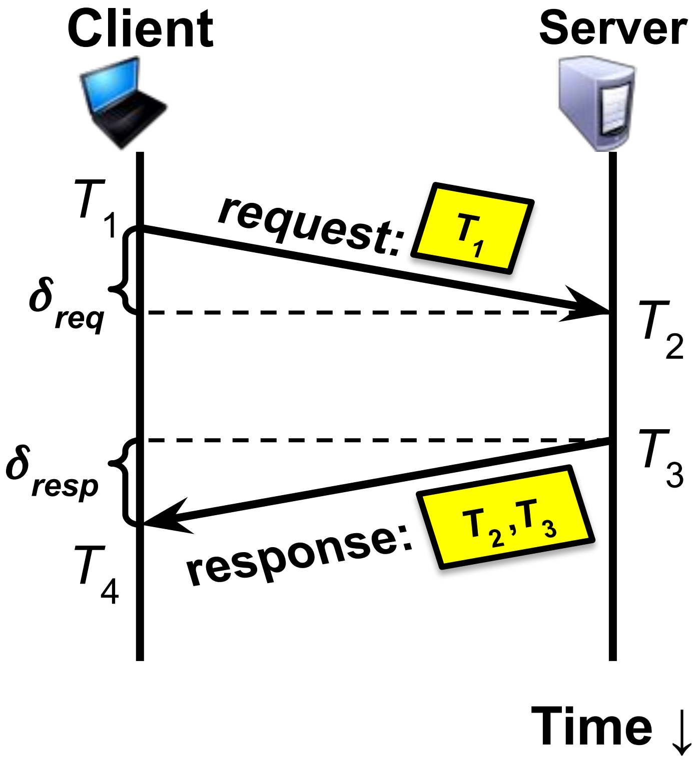
Cristian's algorithm: Offset sample calculation

Goal: Client sets clock ← $T_3 + \delta_{resp}$

- Client samples ***round trip time*** $\delta = \delta_{req} + \delta_{resp} = (T_4 - T_1) - (T_3 - T_2)$
- **But client knows δ, not δ_{resp}**

Assume: $\delta_{req} \approx \delta_{resp}$

Client sets clock ← $T_3 + ½\delta$



Exercise: Cristian's algorithm

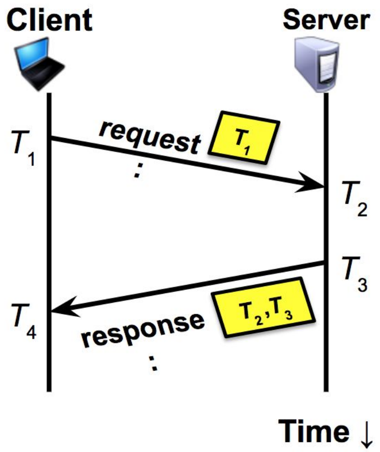
Implement a `CristianServer` that other machines sync their local time to

```
func SyncTime(serverAddr string) (time.Time, error)
```

Set *local time* = $T_3 + RTT/2$, where RTT = $(T_4 - T_1) - (T_3 - T_2)$

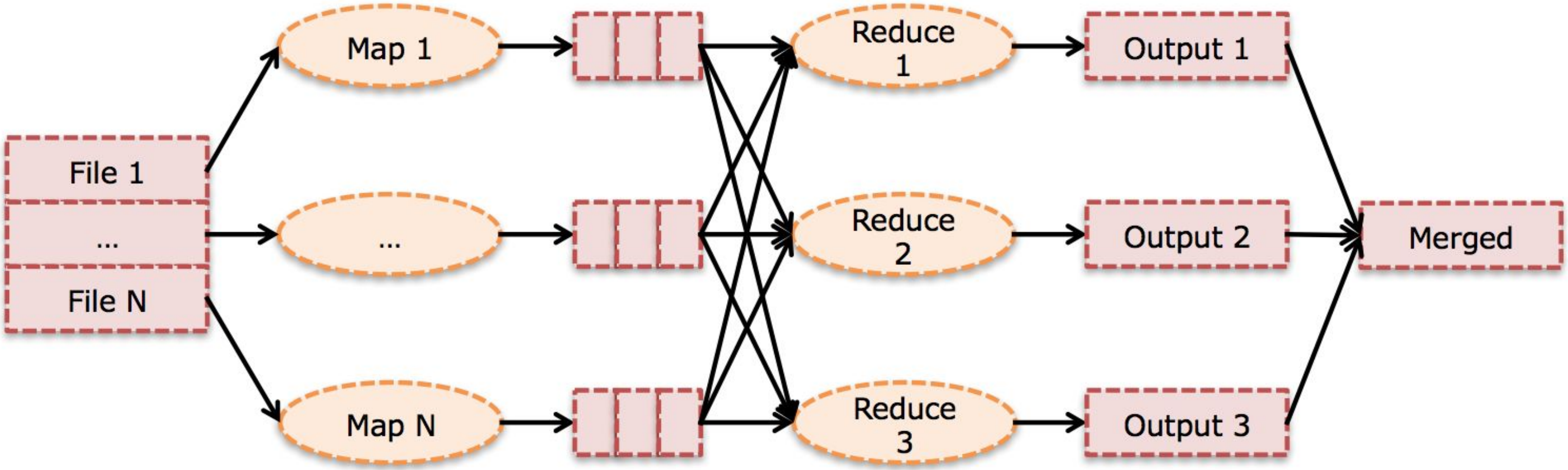
Note: You can just build a simplified version where $T_2 = T_3$

Hint: use `time.Time`'s `Sub` and `Add` methods, `time.Now()`

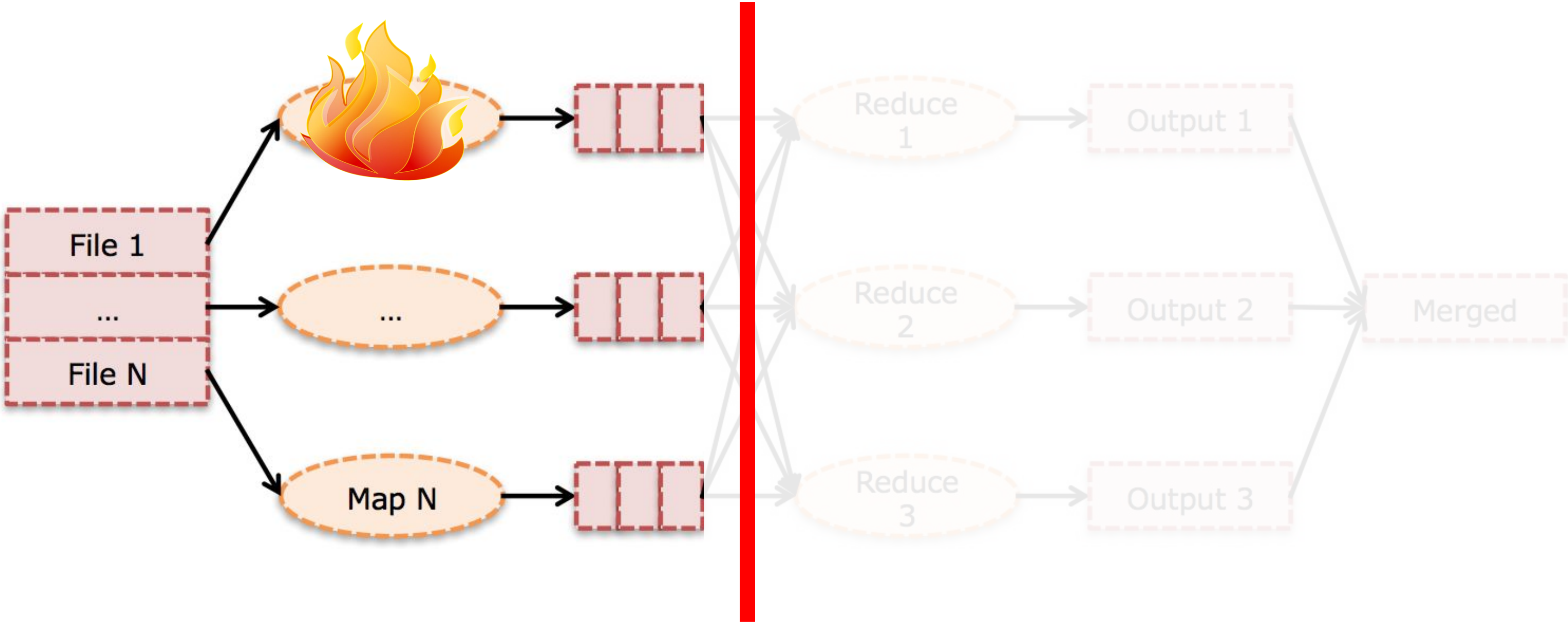


MapReduce: Fault Tolerance and Optimizations

MapReduce: Fault Tolerance

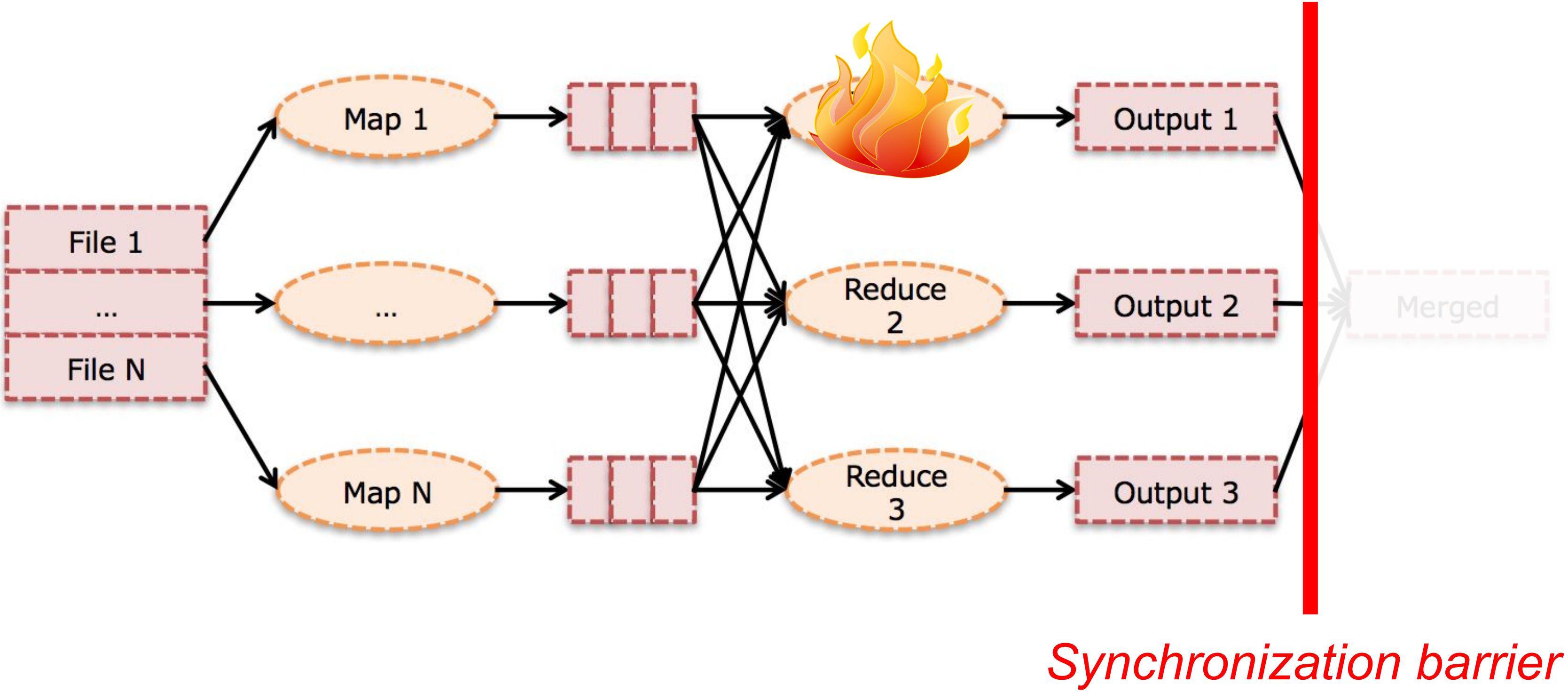


MapReduce: Fault Tolerance

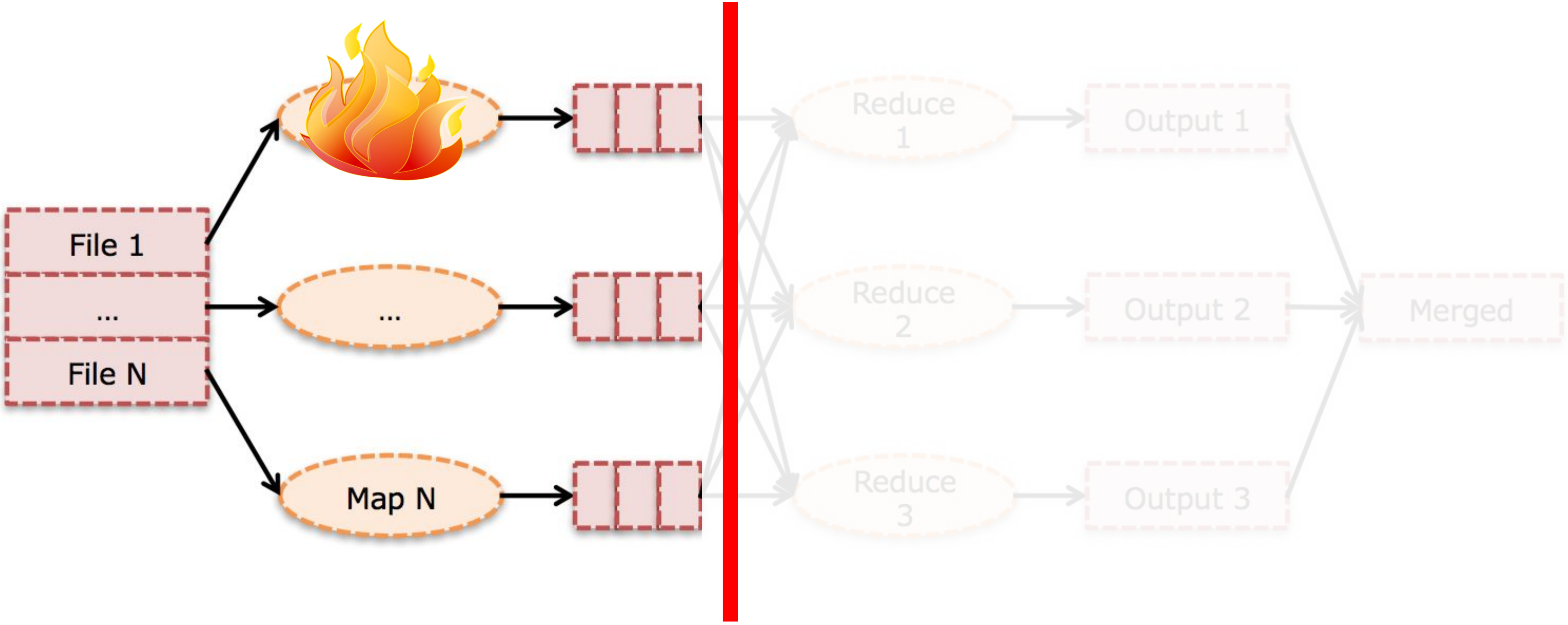


Synchronization barrier

MapReduce: Fault Tolerance

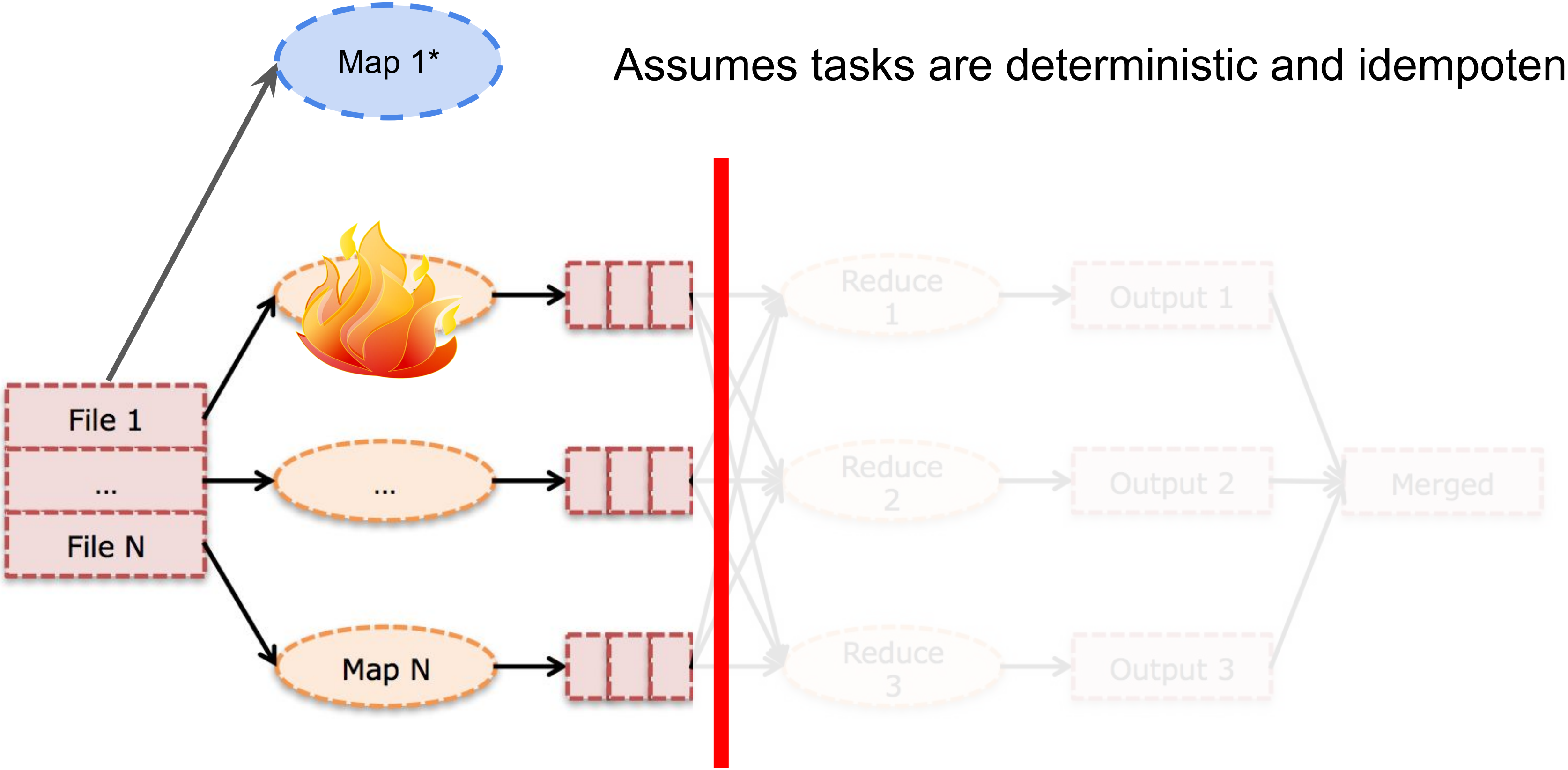


MapReduce: Fault Tolerance

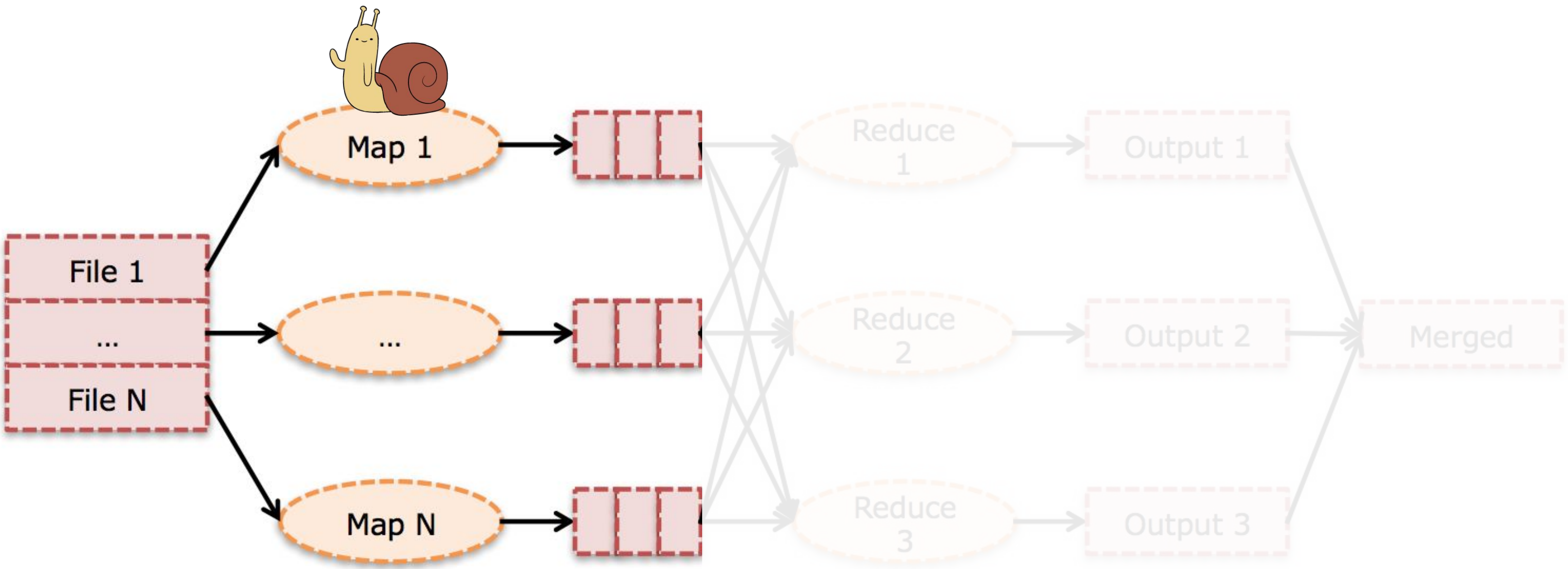


Launch same task on a different machine

Assumes tasks are deterministic and idempotent



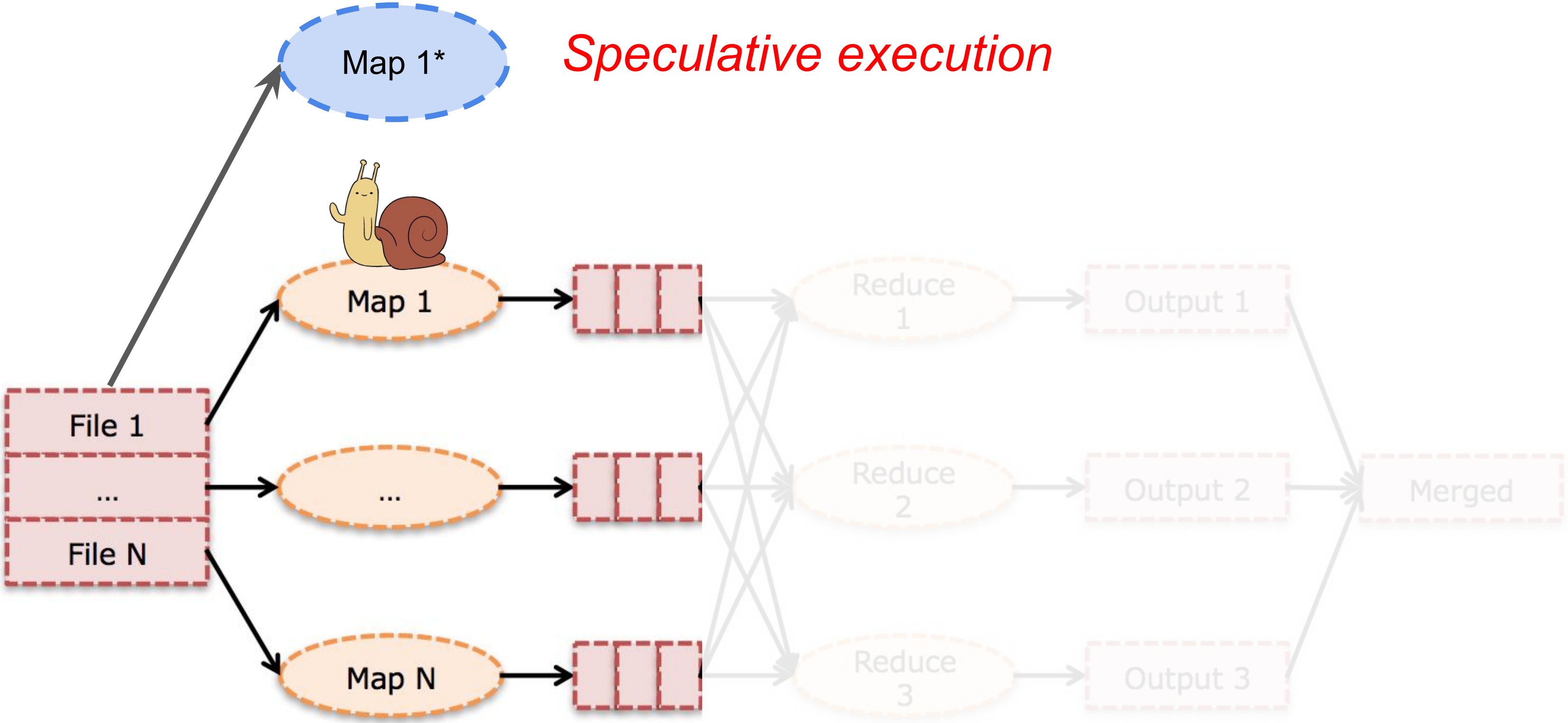
What if server 1 is just *REALLY* slow?



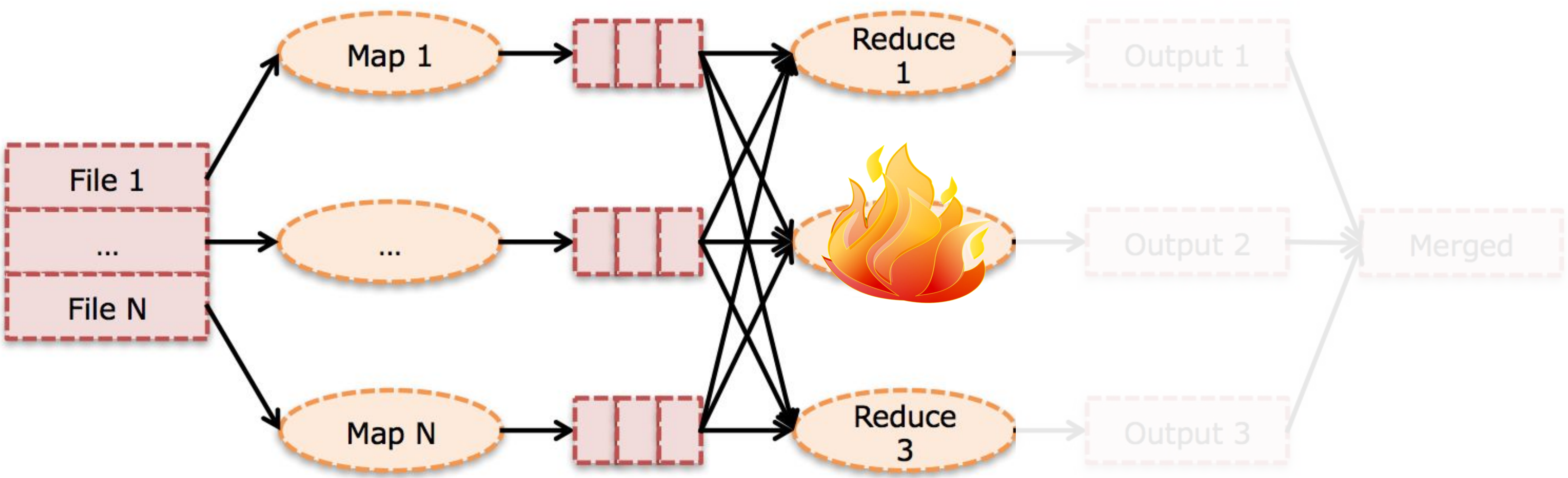
Server 1 is a *straggler*

Use the same idea!

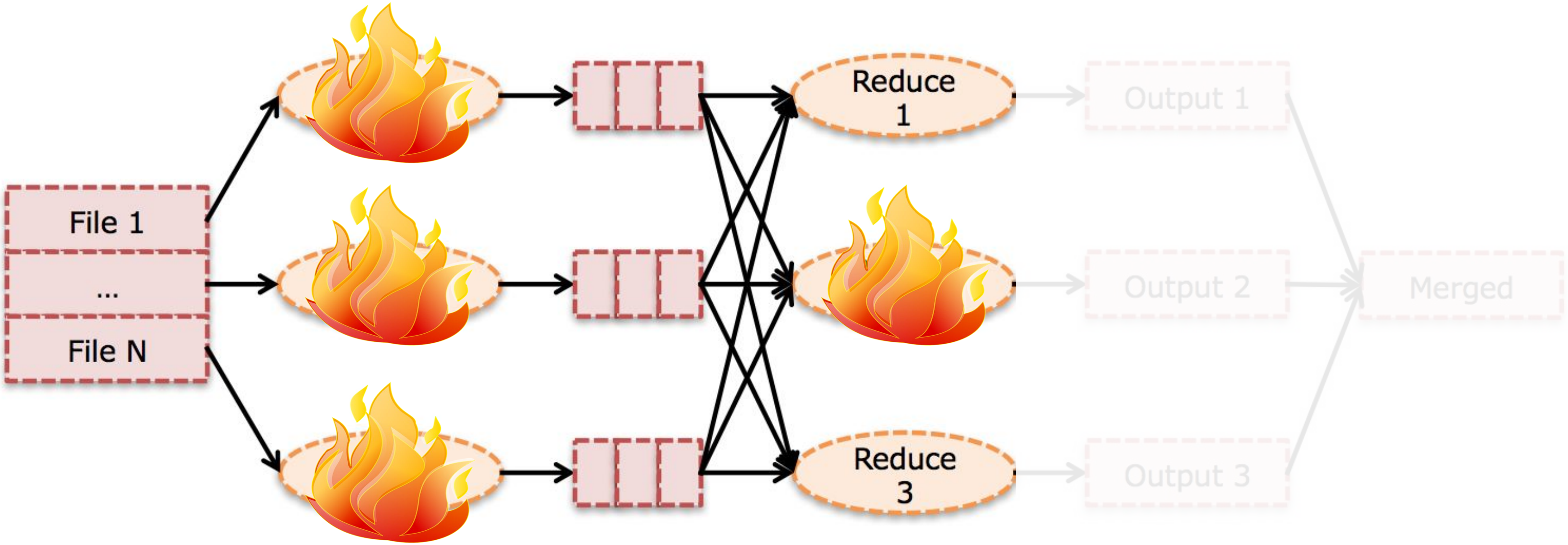
Speculative execution



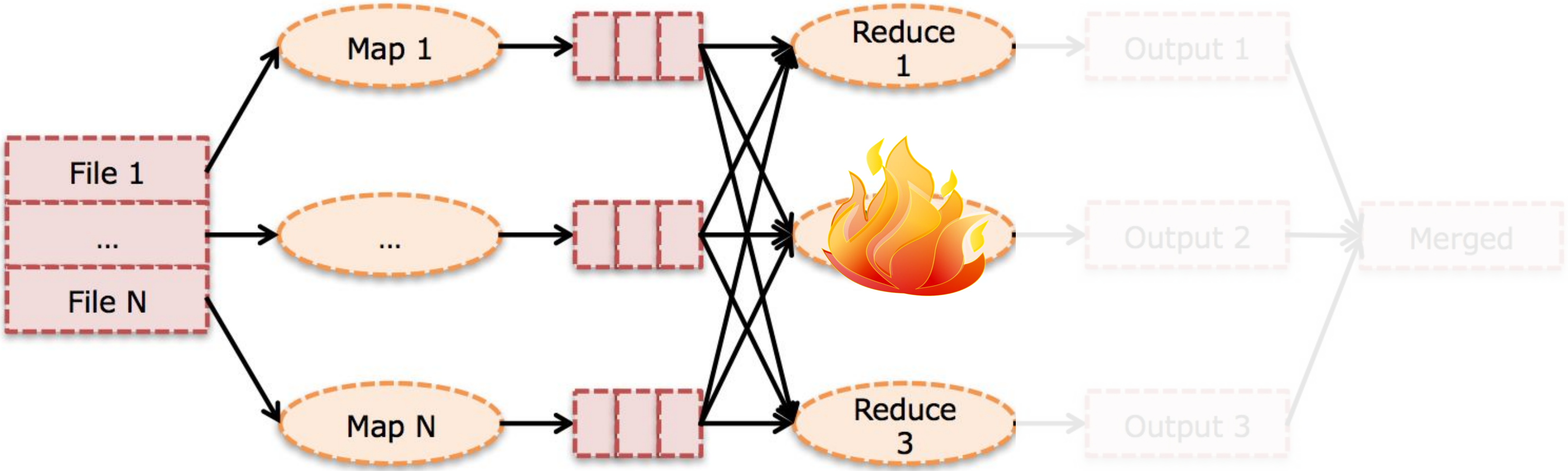
What should we re-execute?



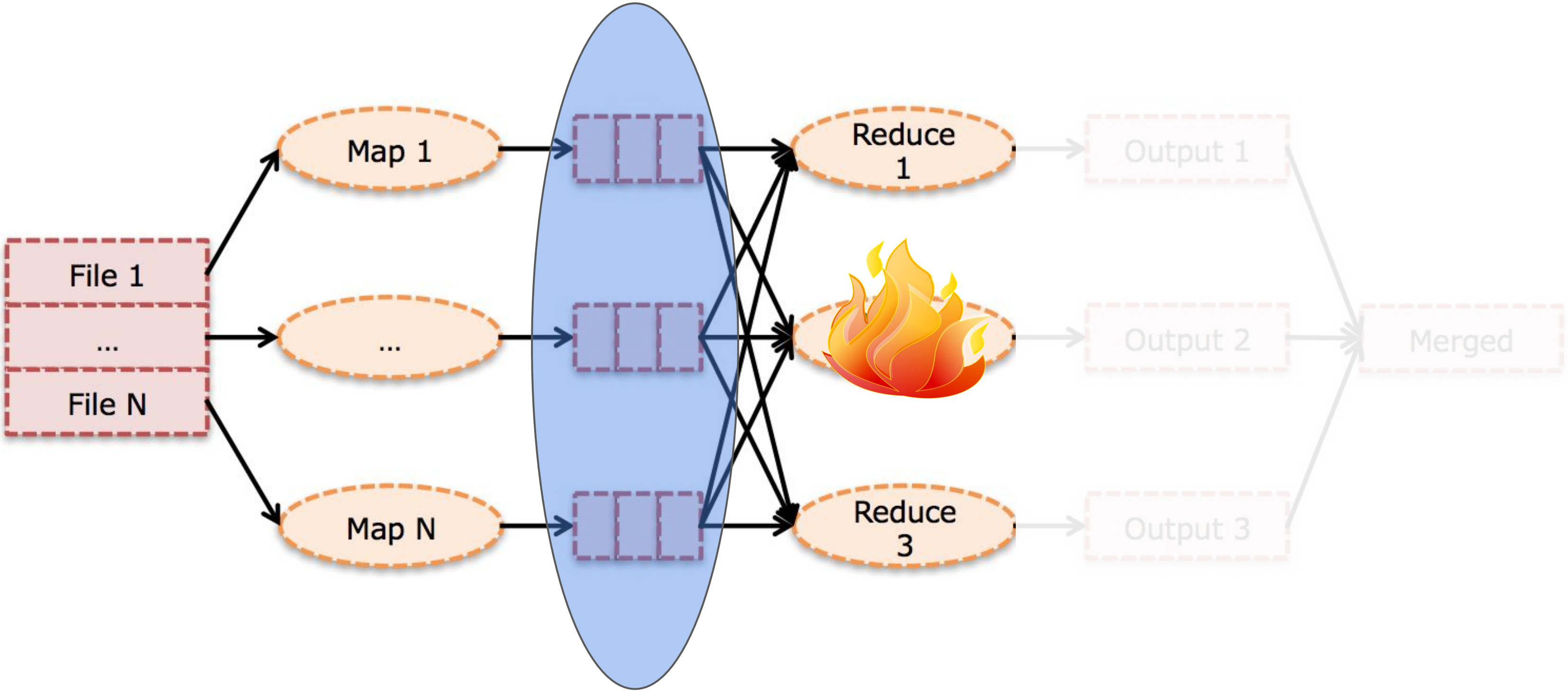
All mappers might provide inputs to Reduce 2



Can we be smarter?

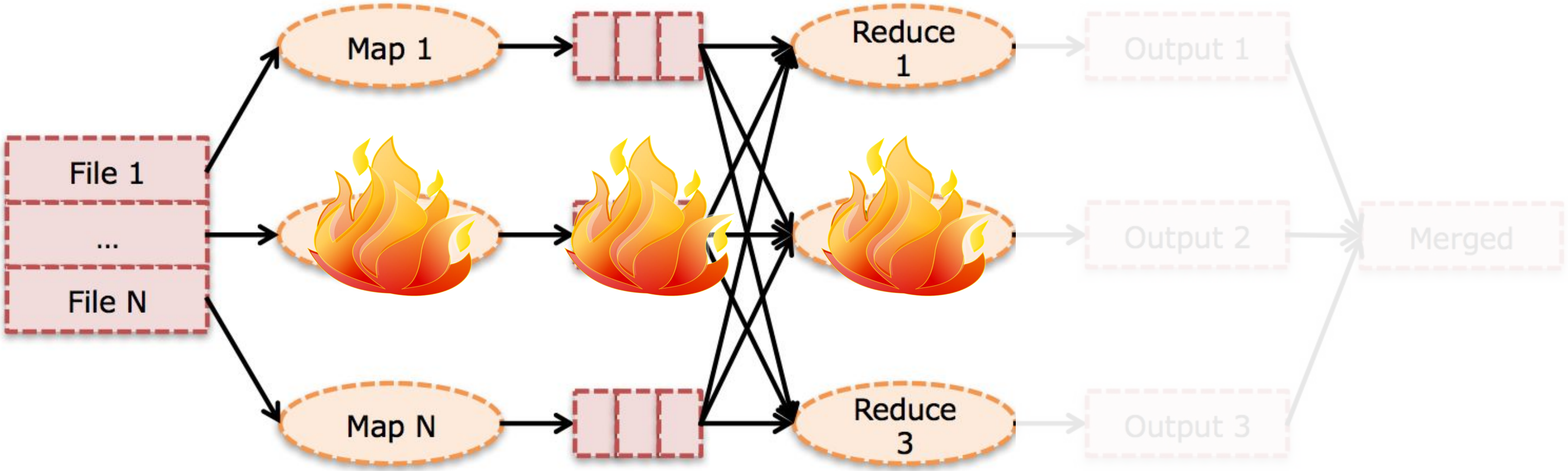


What should we re-execute?

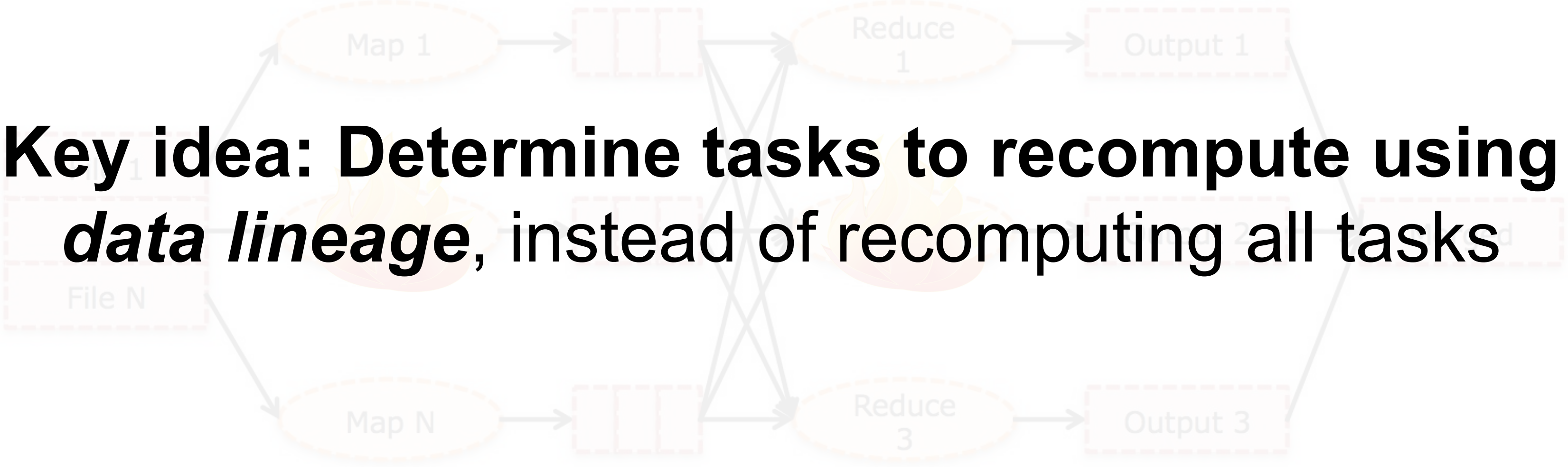


Write intermediate output to stable storage

What could go wrong?

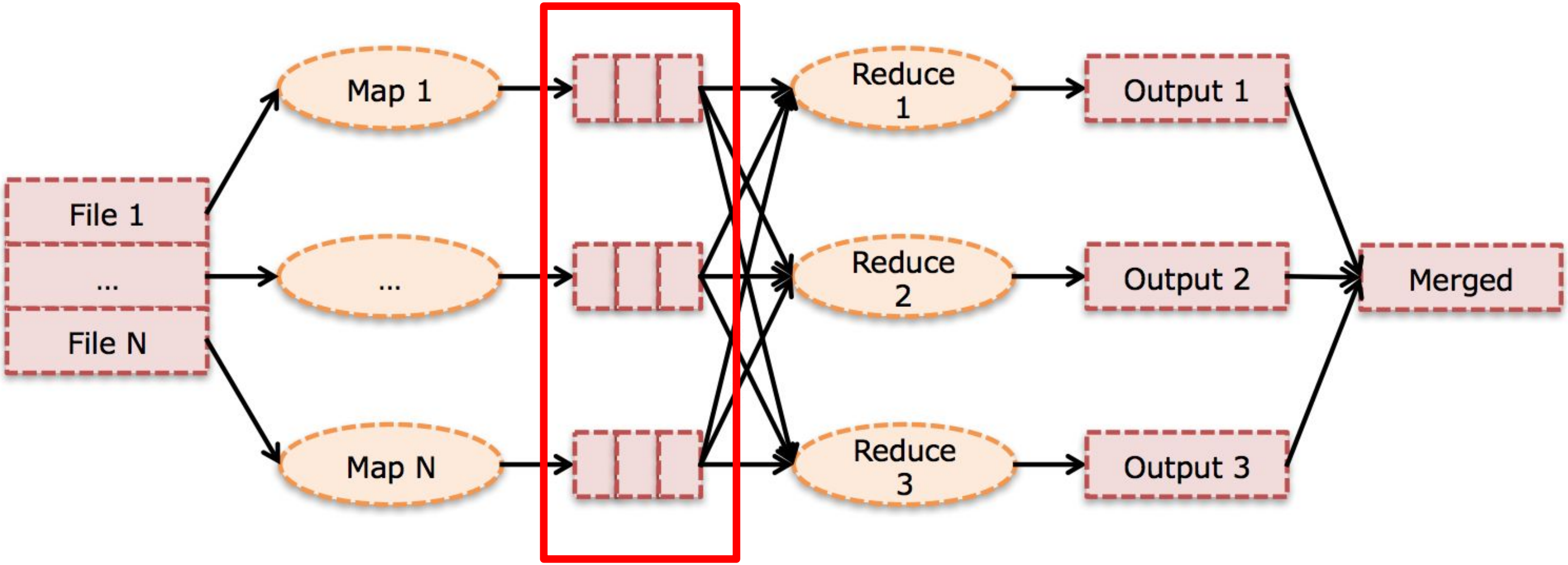


Mapreduce: What could go wrong?



Key idea: Determine tasks to recompute using *data lineage*, instead of recomputing all tasks

Lineage is useful for optimizations too



Reusing map outputs

Job 1:

Job 2: