SpecFaaS: Accelerating Serverless Applications with Speculative Function Execution

HPCA 2023

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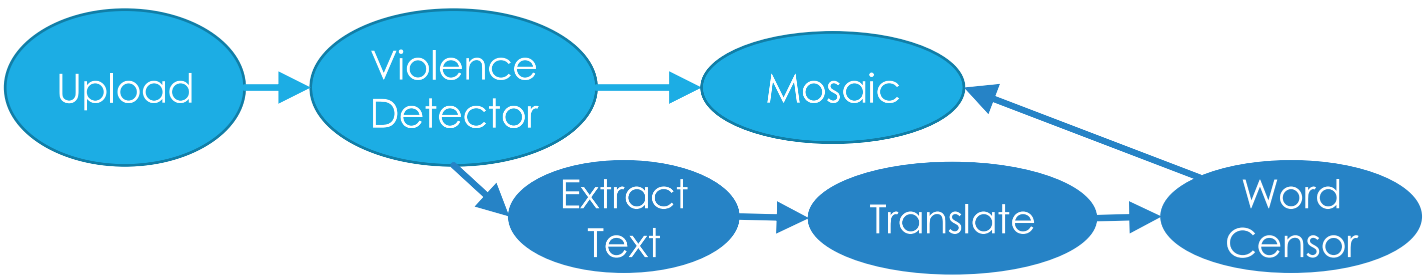
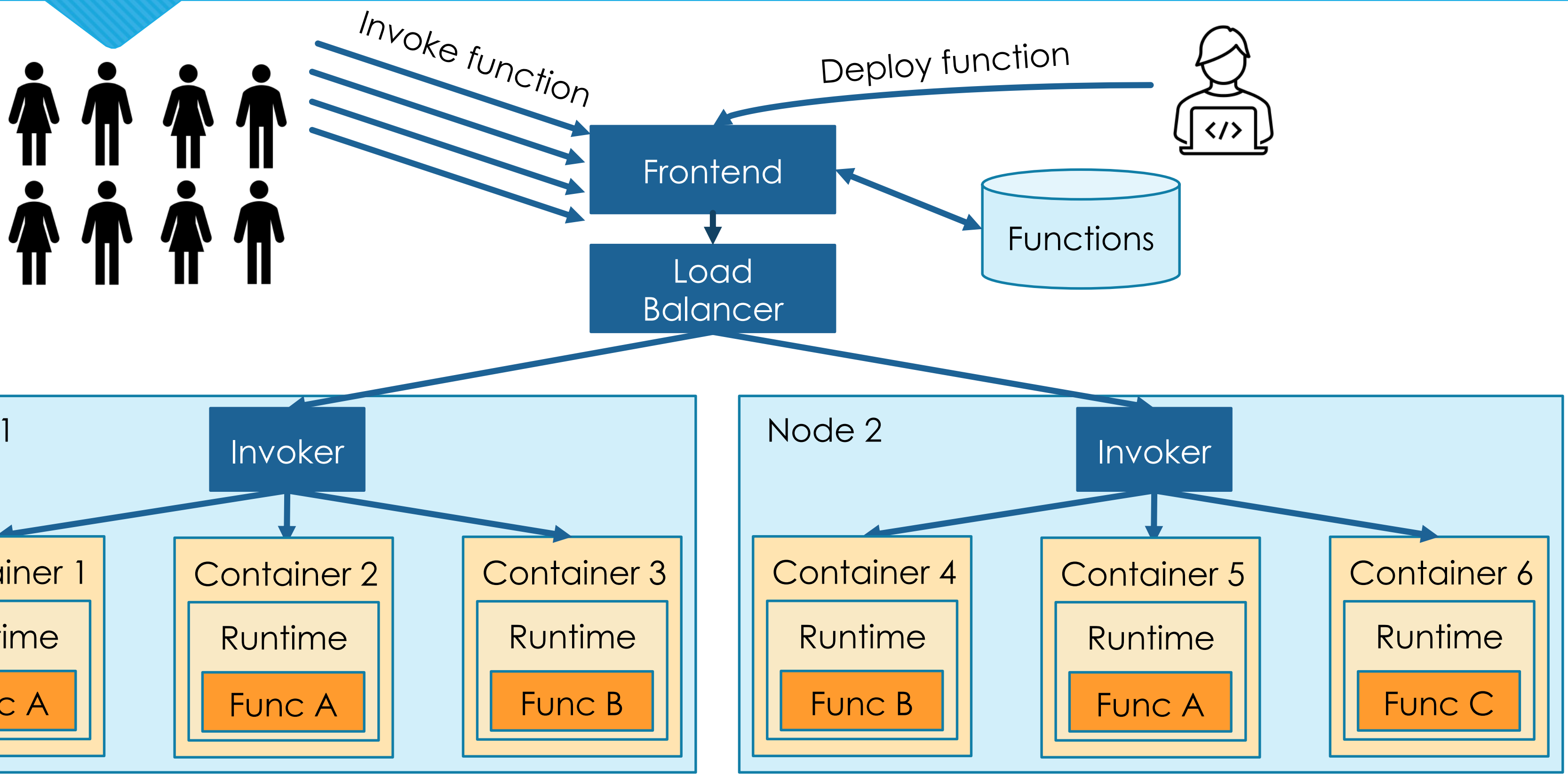
Serverless Computing: Why do we want it?

- Breaking large monolithic applications into many small microservices
  - Ease of programming
  - Elasticity
- Pay-as-you-go model
  - Opportunity for high resource utilization
  - Economic incentives
- AWS Lambda, Microsoft Azure, Google Cloud, IBM Cloud



Serverless Computing: How does it work?



Real-world Applications

- Functions composed into applications with control and data dependences
- Two ways to compose application from functions
  - Explicit workflows
  - Implicit workflows

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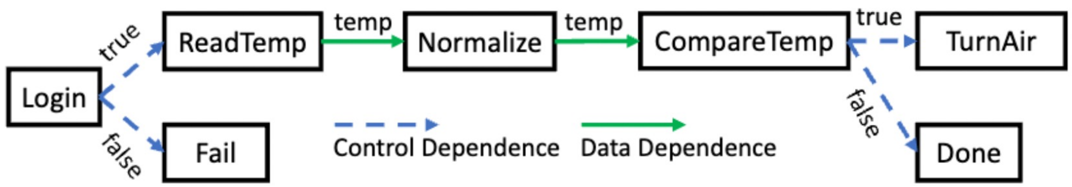


```python
import composer
def main():
    return composer.when('Login',
        composer.sequence(
            'ReadTemp',
            'Normalize',
            composer.when('CompareTemp',
                'TurnAir'),
            'Done'),
        'Fail')
```

Real-world Applications

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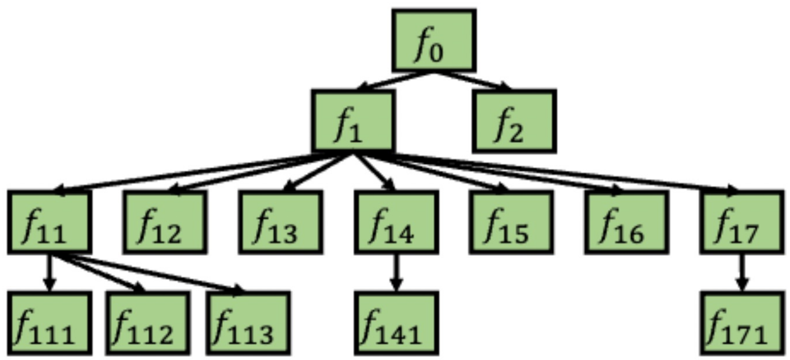
  - **Implicit workflows**



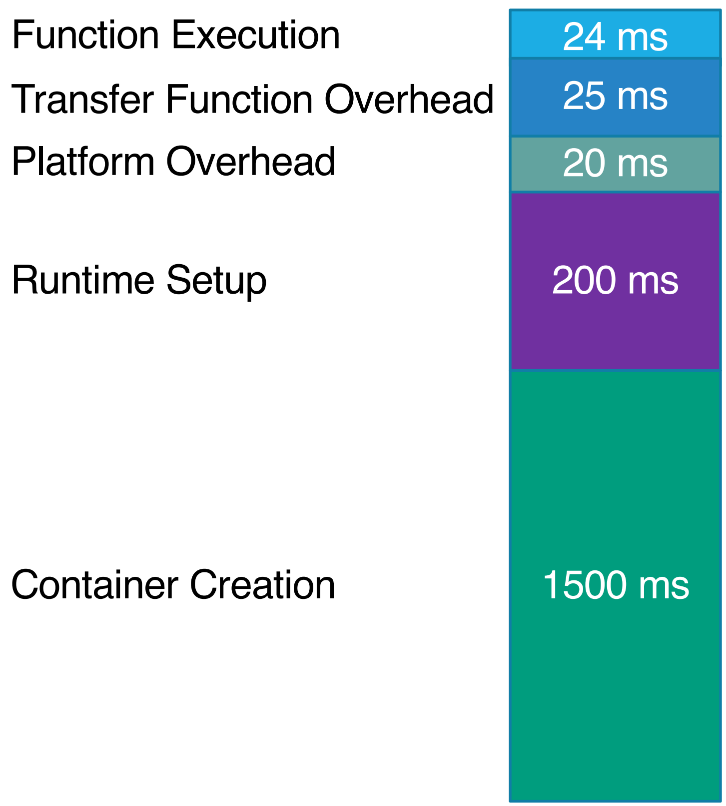
Contributions

- Characterization of serverless environments
- Propose **SpecFaaS** – novel serverless execution model based on speculation
  - Functions execute before their control and data dependences are resolved
  - Control dependences are predicted with branch prediction
  - Data dependences are speculatively satisfied with memoization
- Average speedup 4.6X

Outline of this talk

- **Characterization of Serverless Environments**
- SpecFaaS: Speculative Execution Engine of Serverless Applications
  - SpecFaaS Design and Implementation
  - SpecFaaS Key Results
- Conclusion

Short Functions, Huge Overheads



Platform: OpenWhisk
Applications: TrainTicket

Short Functions, Huge Overheads

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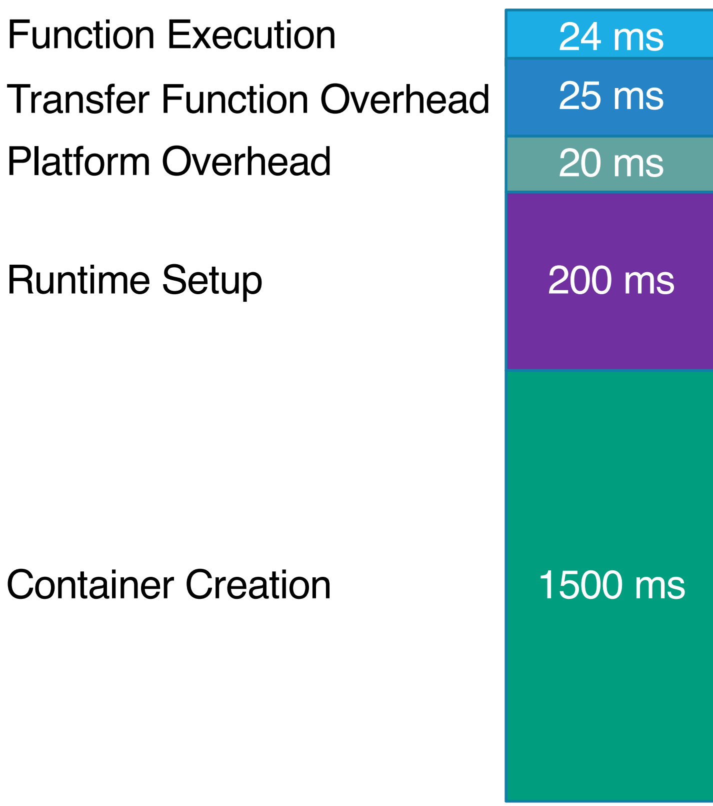
Applications: TrainTicket

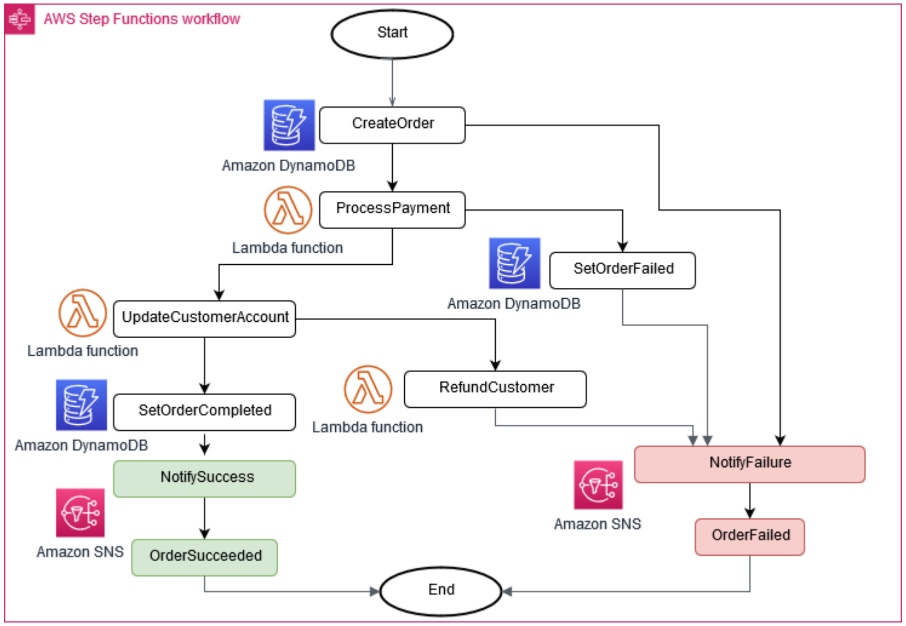


2s overhead for 20ms execution!

Can we minimize and/or overlap overheads?
Can we even overlap executions?

Control Dependences are Predictable

- Branches and conditional function calls create workflow divergence
- Sequence of functions highly predictable
  - Exception and error handling code rarely executed
  - Most popular sequence accounts for
    - 90% of invocations with Alibaba
    - 98% of invocations with TrainTicket



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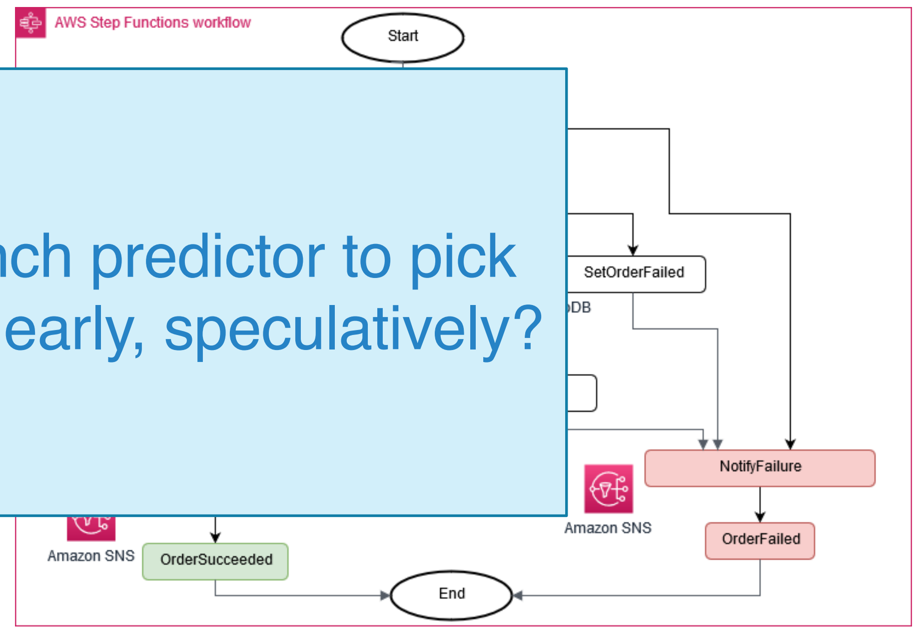
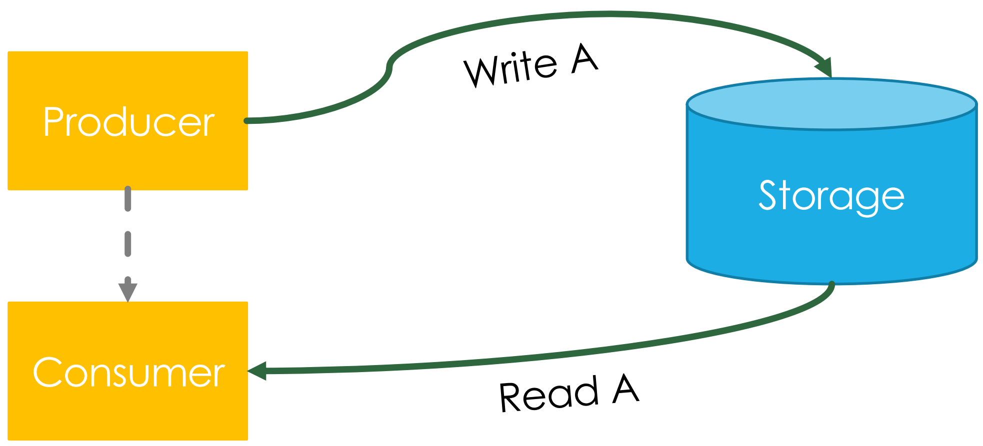


Can we develop a SW branch predictor to pick the next function to execute early, speculatively?

Data Dependences are Rare

- Functions can communicate via remote storage
- Remote storage is not frequently updated
  - Azure Blob storage traces: only 23% writes, 66% of blobs never updated
- Reads and writes to the same location are well separated
  - Azure Blob storage traces: 96% more than 1s, 27% more than 10s



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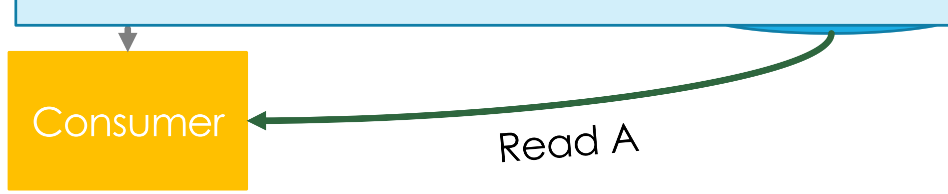
  - Azure
- Reads an
  - Azure

Can we predict data dependences between functions without frequent squashing?



Data Dependences are often Predictable

- Most functions don’t read from writable storage, don’t write to storage
  - 76% for TrainTicket, 85% for FaaSChain
- Pure functions: stateless + deterministic
  - Guaranteed to produce the same outputs whenever invoked with the same inputs

```
@Override
public mResponse queryForId(String stationName) {
    Station station = repository.findByName(stationName);
    if (station  != null) {
        return new mResponse<>(1, success, station.getId());
    } else {
        return new mResponse<>(0, "Not exists", stationName);
    }
}
```

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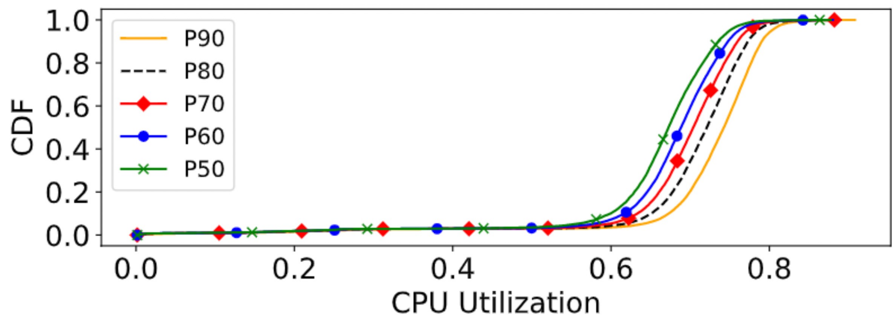
}
```

Can we memoize current input/output mapping and later use it for speculative predictions?

Side Effects not Diverse, CPUs Poorly Utilized

- Only few types of side-effects
  - Functions meant to be executed anywhere, should not carry/modify any local OS state
  - 110 open-source functions: writes to remote storage, writes to local files, HTTP
- CPUs are not fully utilized in the cloud
  - Need to handle load spikes and be prepared for the worst-case scenario
  - Alibaba Cloud: CPUs always in the range 60-80%



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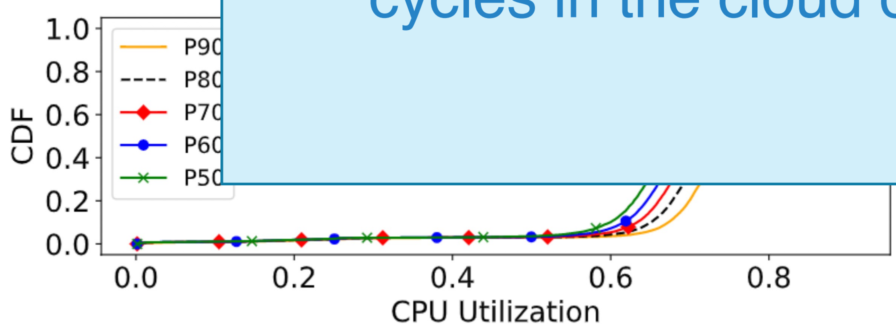

Can we waste some of the abundant idle CPU cycles in the cloud on mis-speculation?

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- **SpecFaaS: Speculative Execution Engine of Serverless Applications**
  - SpecFaaS Design and Implementation
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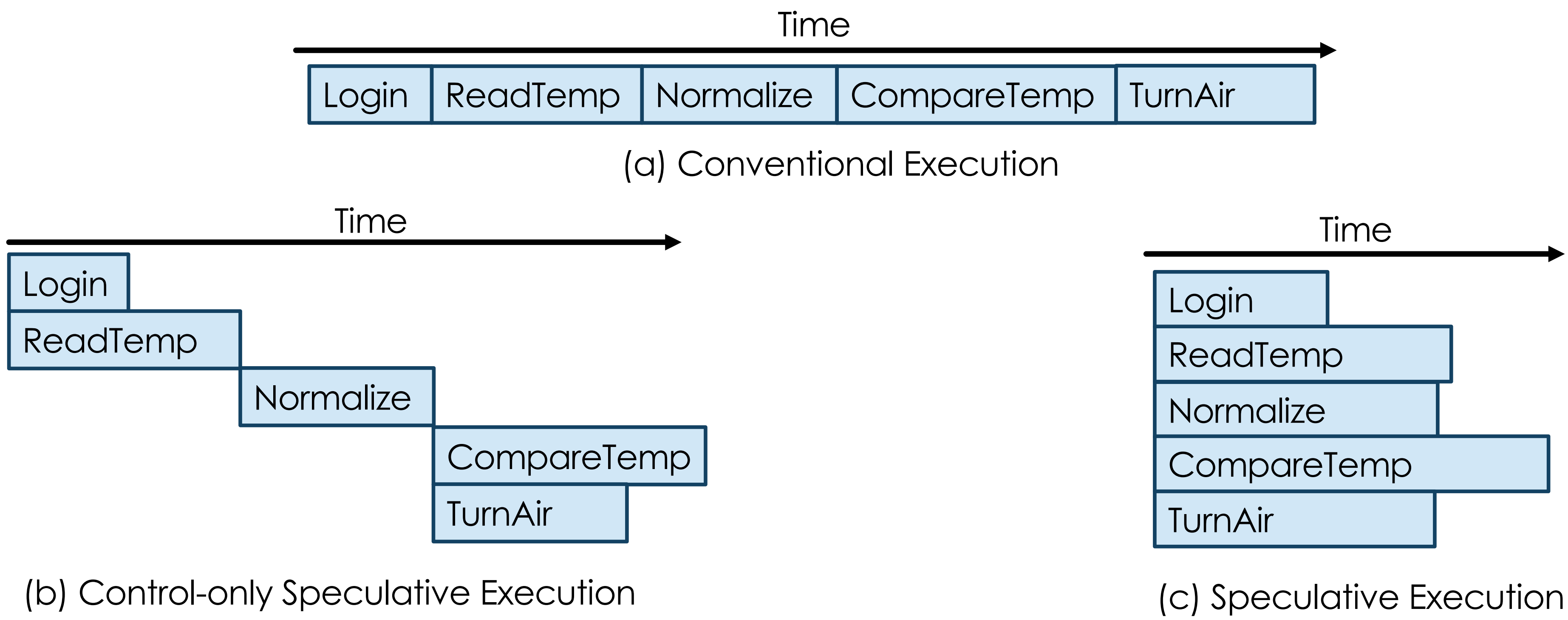
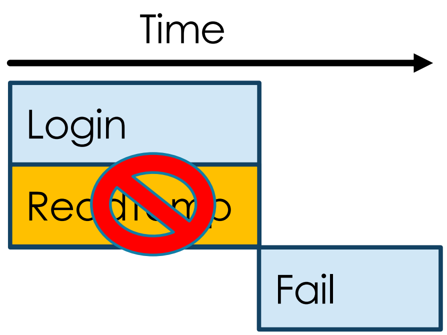
SpecFaaS Overview: Executing Beyond Dependences

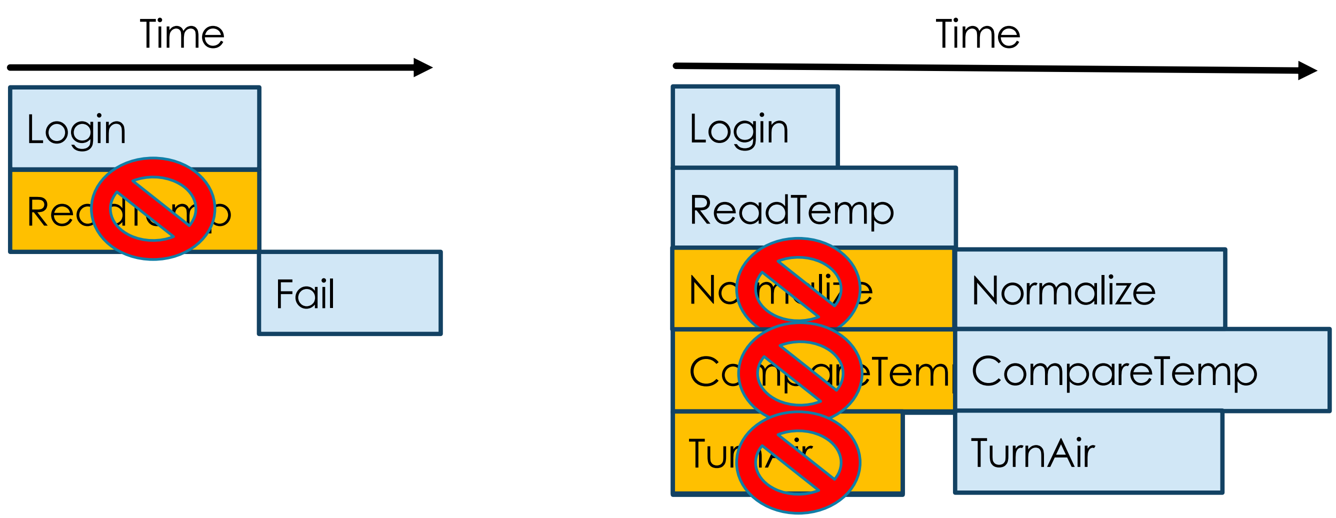


SpecFaaS Overview: Squashing on Mis-speculation



(a) Control mis-speculation

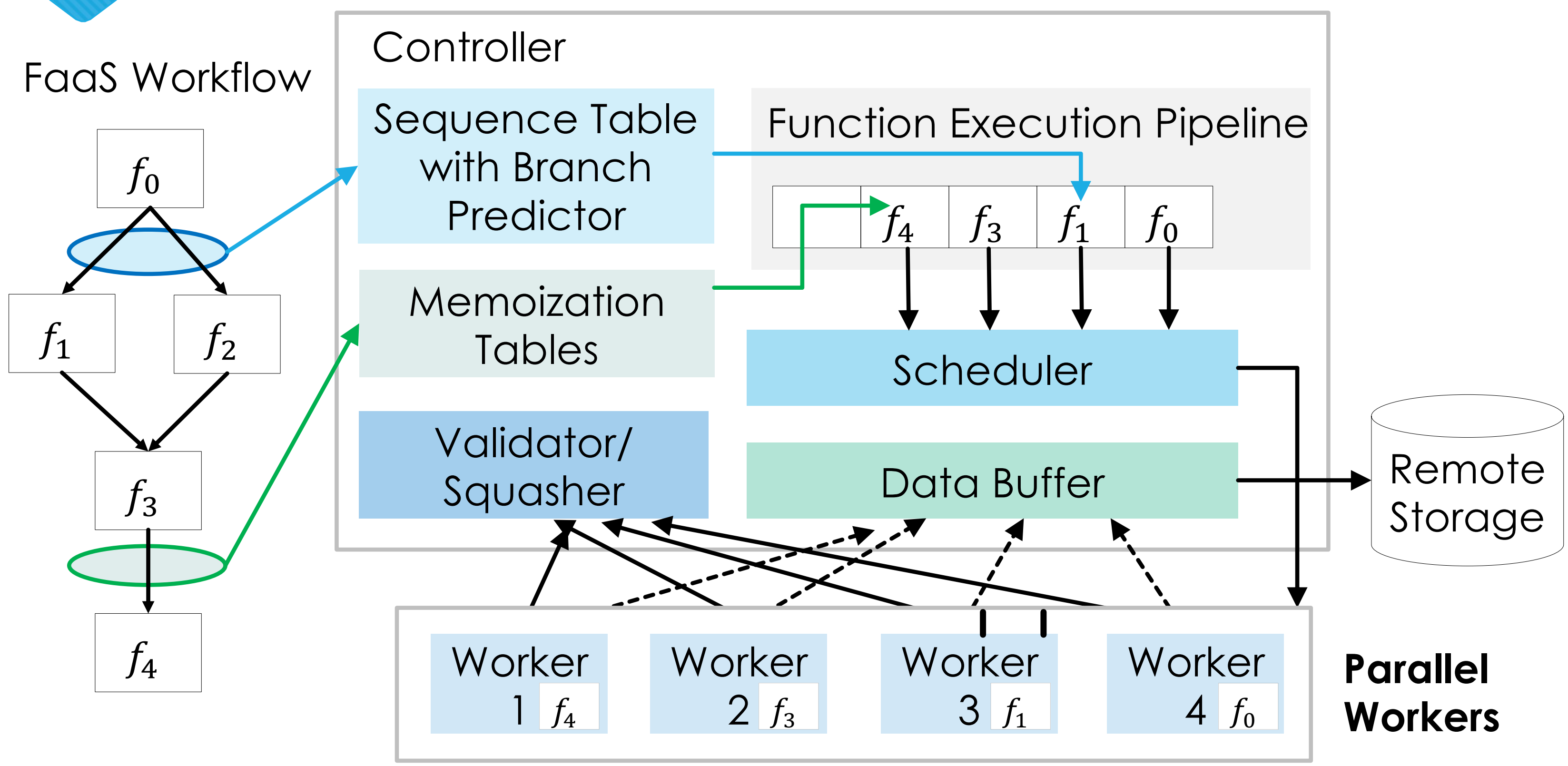
SpecFaaS Overview: Squashing on Mis-speculation



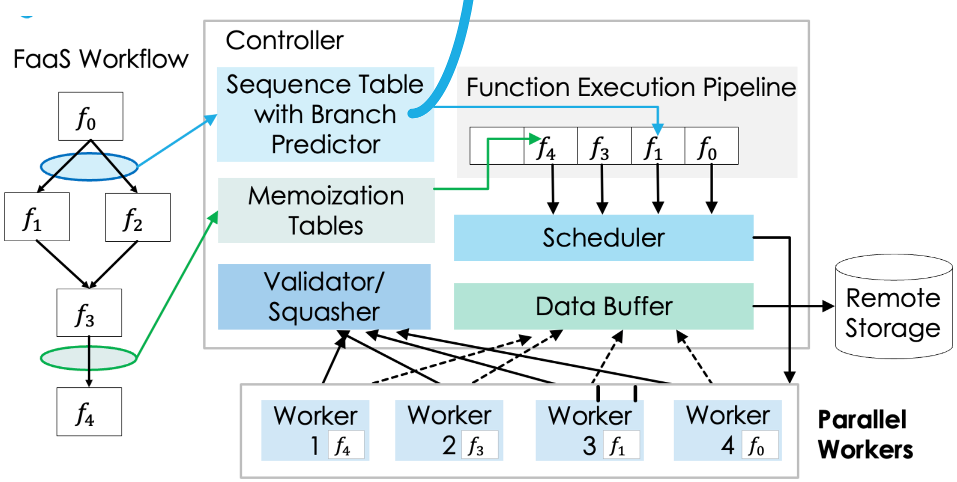
(a) Control mis-speculation

(b) Data mis-speculation

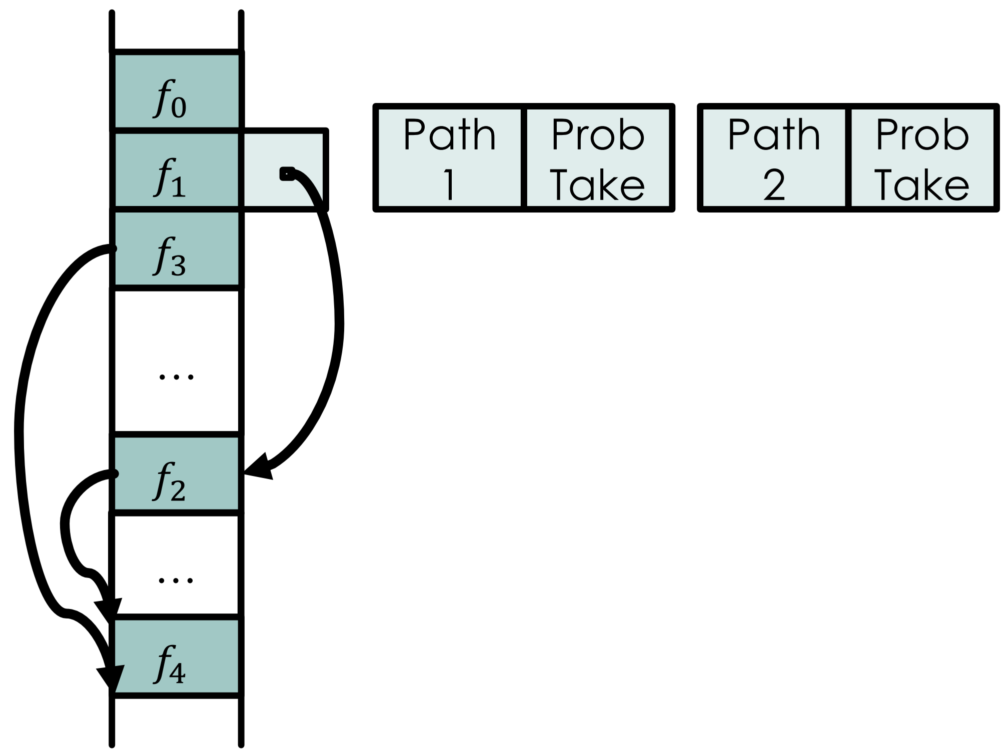
SpecFaaS Design: High-Level Overview



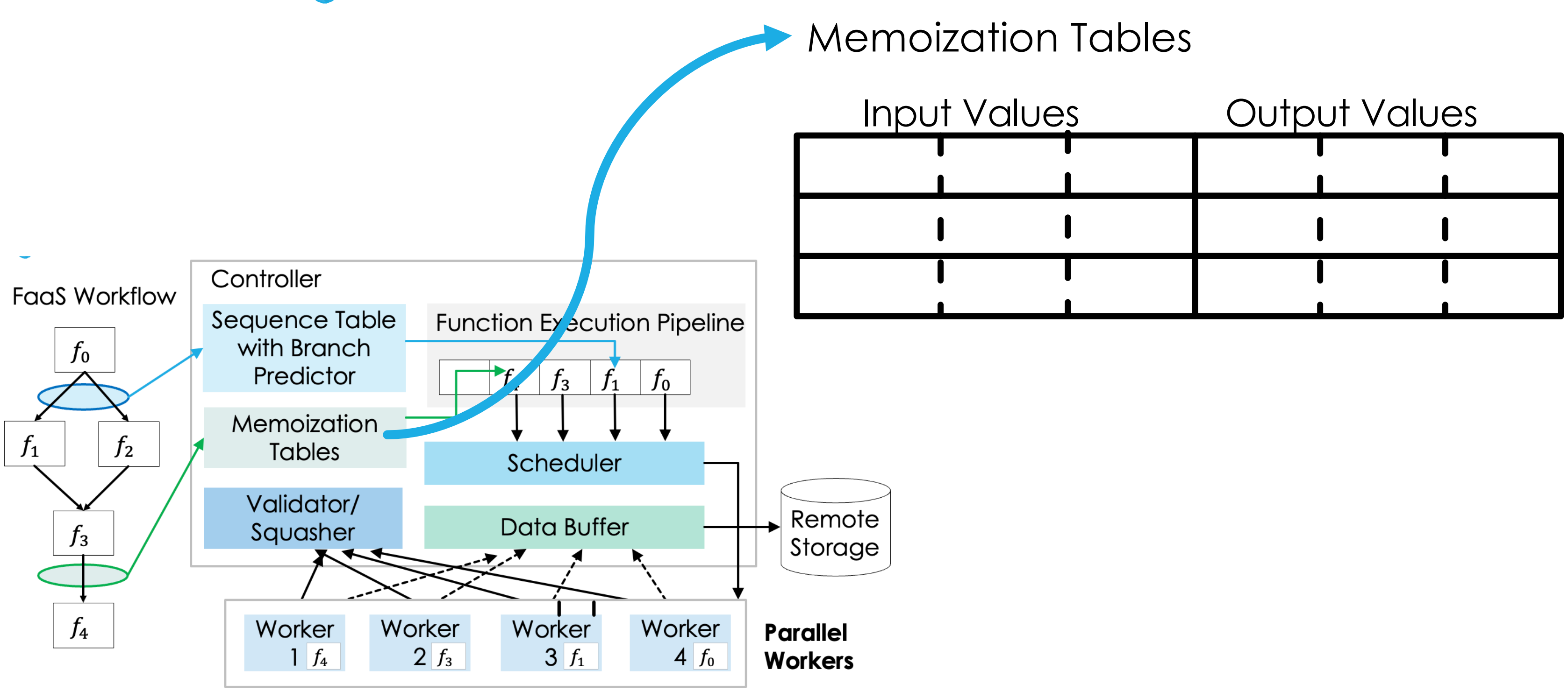
SpecFaaS Design:
Sequence Table with Branch Predictor



Sequence Table with Branch Predictor



SpecFaaS Design: Memoization Table and Data Buffer



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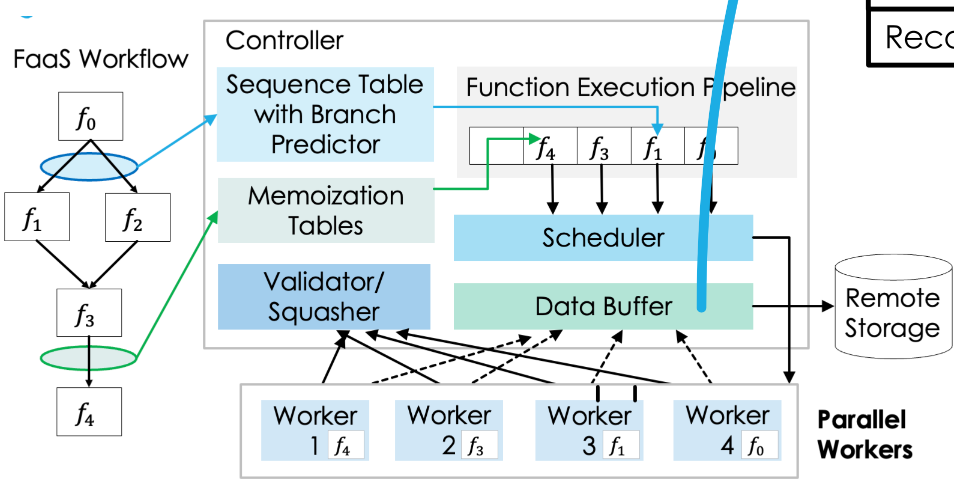

Data Buffer

Address	*Function* $i-1$				*Function* i				*Function* $i+1$			
	V	R	W	Data	V	R	W	Data	V	R	W	Data
Record 1	1		1	Value 1								
Record 2									1	1		Value 2

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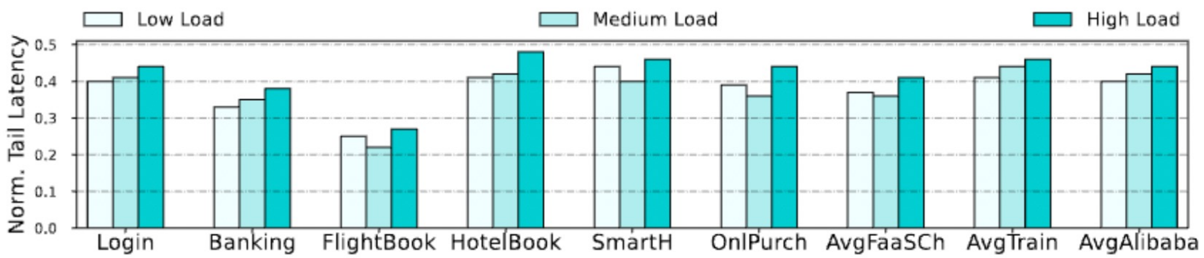
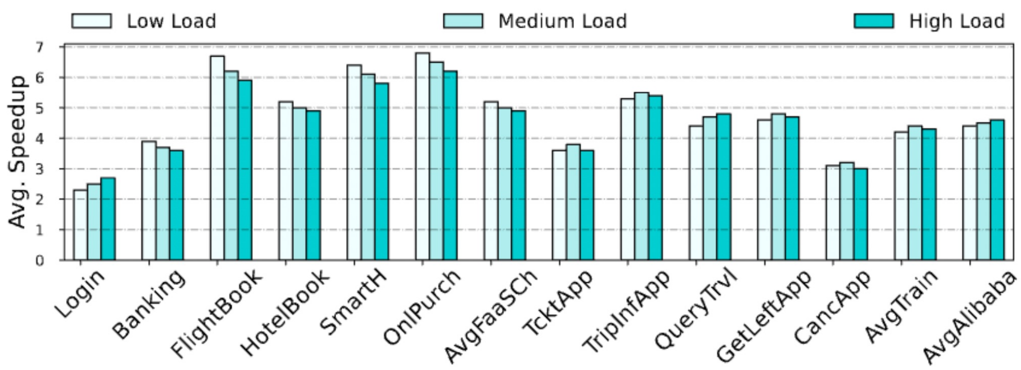
SpecFaaS: Key Results

- Average speedup 4.6X
- Tail latency reduced 2.4X
- Throughput increased 3.9X





HitRate	Baseline	NoSquash	SpecFaaS	Speedup
100%	1	1	1	5.2X
90%	1	1.09	1.03	5.0X
70%	1	1.24	1.08	4.6X
50%	1	1.43	1.15	4.0X

Conclusion

- Serverless computing brings benefits but its execution is inefficient
- Propose **SpecFaaS** – novel serverless execution model based on speculation for performance
  - Functions execute before their control and data dependences are resolved
  - Control dependences are predicted with branch prediction
  - Data dependences are speculatively satisfied with memorization
  - Data Buffer buffers speculative updates and prevents them from being externalized before speculative function is committed
- Average speedup 4.6X

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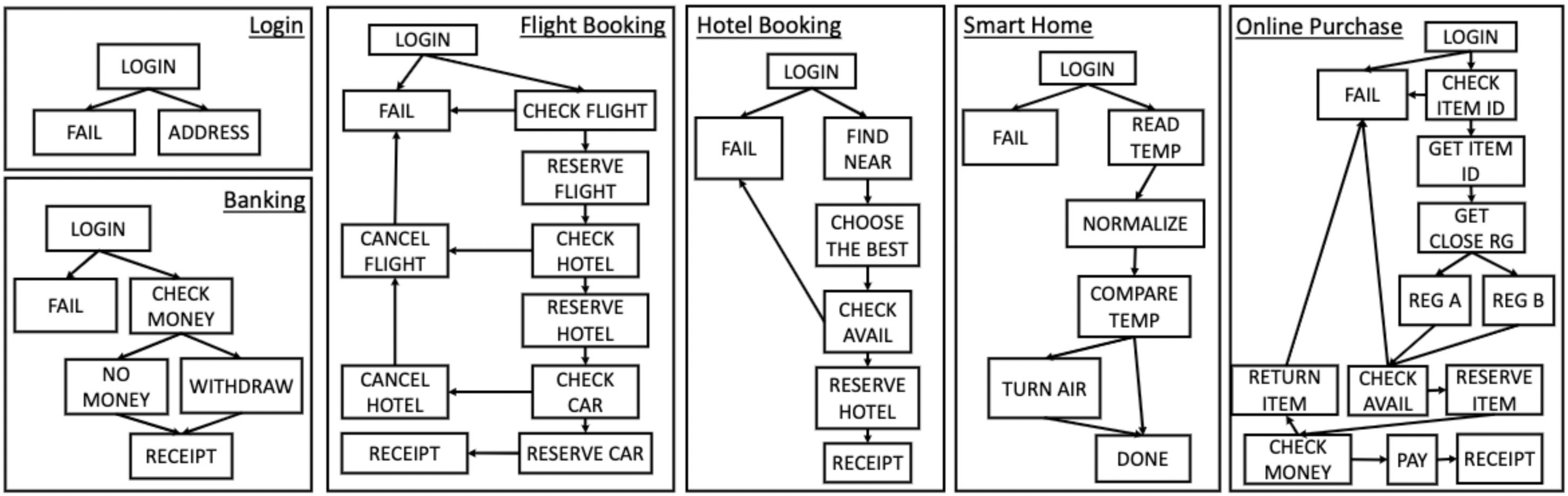
SpecFaaS: More in the Paper!

- Efficient support for implicit workflows
- Minimizing cost and frequency of mis-speculation
- Handling different side-effects
- …

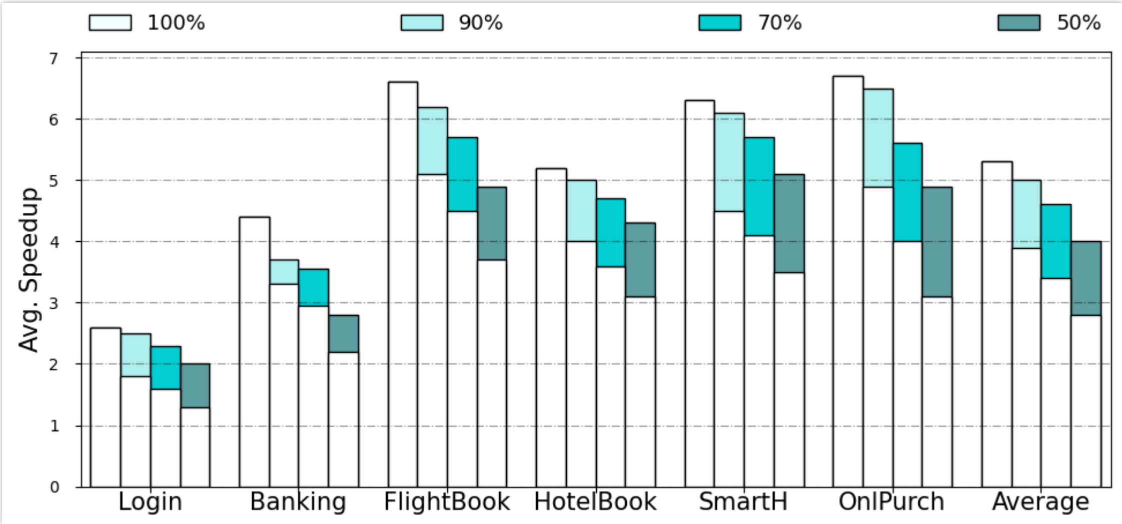
Backup Slides: FaaSChain Applications



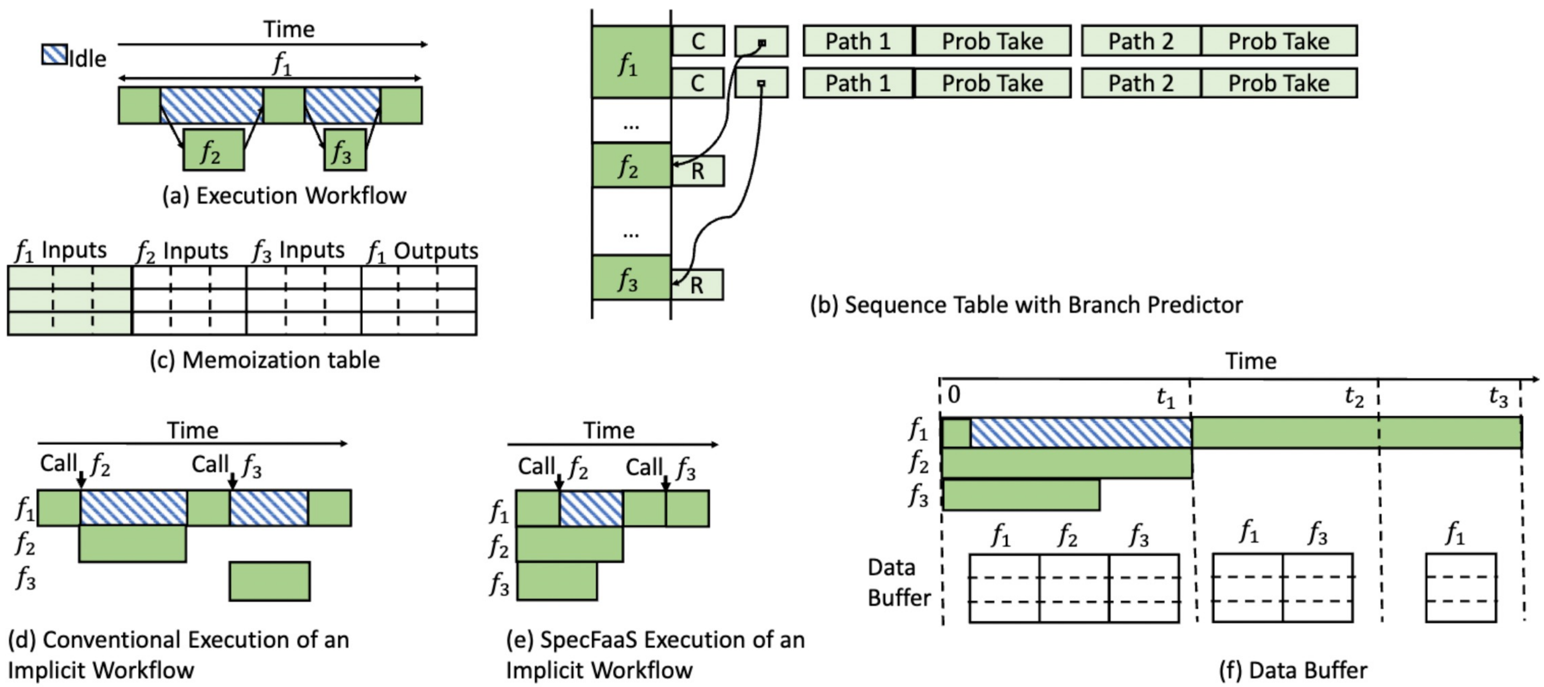
Backup Slides: SpecFaaS Branch Predictor Sensitivity

Average Speedup (FaaSChain):
- 100% hit rate = 5.2X
- 90% hit rate = 5X
- 70% hit rate = 4.6X
- 50% hit rate = 4X

Improvement due to squash optimization
- 90% hit rate = 1.28X
- 70% hit rate = 1.35X
- 50% hit rate = 1.43X



Backup Slides: SpecFaaS Support for Implicit Workflows



Backup Slides: SpecFaaS Mis-Speculation Handling

- Main challenge with SpecFaaS: it becomes expensive on mis-speculation
- There are 3 options
- **Option 1**: Let the mis-speculated function request (invocation) finish in the background and ignore all its global updates
  - No squashing, uses precious CPU cycles
- **Option 2**: Squash the function request by killing the container
  - No waste of CPU cycles, expensive squash operation (stopping the container ~10s in the background + cannot reuse container for latter invocations)
- **Option 3**: Squash the function request by killing the handler process
  - No waste of CPU cycles, cheap squash operation (~1ms), can reuse container

Backup Slides:
SpecFaaS Side-Effects Handling

- Three main sources of side-effects
  - Writing to global storage, writing to local files, sending HTTP requests
- SpecFaaS able to deal with writes to the global storage via Data Buffer
- Writing to local files → CoW for Files (intercept file syscalls)
  - For every request (invocation) we start with the initial shared files
  - As long as the request only reads from the files, it uses the original files
  - Once the request tries to write to the file, it gets its own temp copy of the file
  - When the request completes its execution discard all temporary files
- Sending HTTP requests → Stall (intercept sendto syscall)
  - Once we detect a request tries to send data via socket, we stall the operation until the request becomes non-speculative

Backup Slides: SpecFaaS Producer-Consumer Handling

- Functions can communicate over the storage when data is larger than the allowed input size defined by the FaaS platform
  - FuncA producer writes to the storage, FuncB consumer reads from the storage
- If a consumer prematurely reads from the storage → need to squash it (used stale data)
- Controller can detect that a function is frequently squashed due to RAW dependence violation → introduce STALL operation
- Avoid squashing by stalling until data becomes available
  - Previous writer/producer wrote to the storage (data buffer)
  - Previous writer/producer completed its execution