Architecting Trigger-Action Platforms for Security, Performance and Functionality

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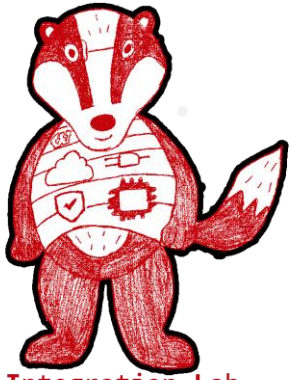
Systems, Cloud, and Architecture



Integration Lab

Trigger-Action Platforms

User

Trigger-Action Platforms

Trigger Services (Event Sources)

User

Trigger-Action Platforms

Trigger Services (Event Sources)

Action Services (Event Sinks)

User

Trigger-Action Platforms

Trigger Services (Event Sources)

Event Processing + Forwarding

Action Services (Event Sinks)

User

Trigger-Action Platforms

Trigger Service (Office365)

Action Service (Dropbox)

If email subject contains “IFTTT” then append email body to file “processed.txt”

User

Trigger-Action Platforms

Trigger Service (Office365)

Action Service (Dropbox)

If email subject contains “IFTTT” then append email body to file “processed.txt”

```
var searchResult = Office365Mail.newEmailFrom.Subject.search("IFTTT");

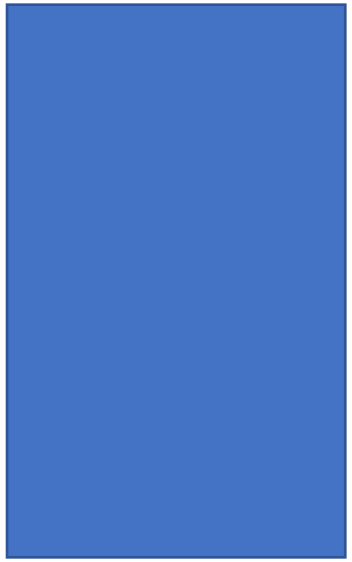
if (searchResult != -1) {
    Dropbox.appendToTextFileDb.append(Office365Mail.newEmailFrom.Body, "processed.txt");
} else {
    Dropbox.appendToTextFileDb.skip();
}
```

User

Trigger-Action Platforms

Trigger Service (Office365)

Trigger Action Platform (TAP)



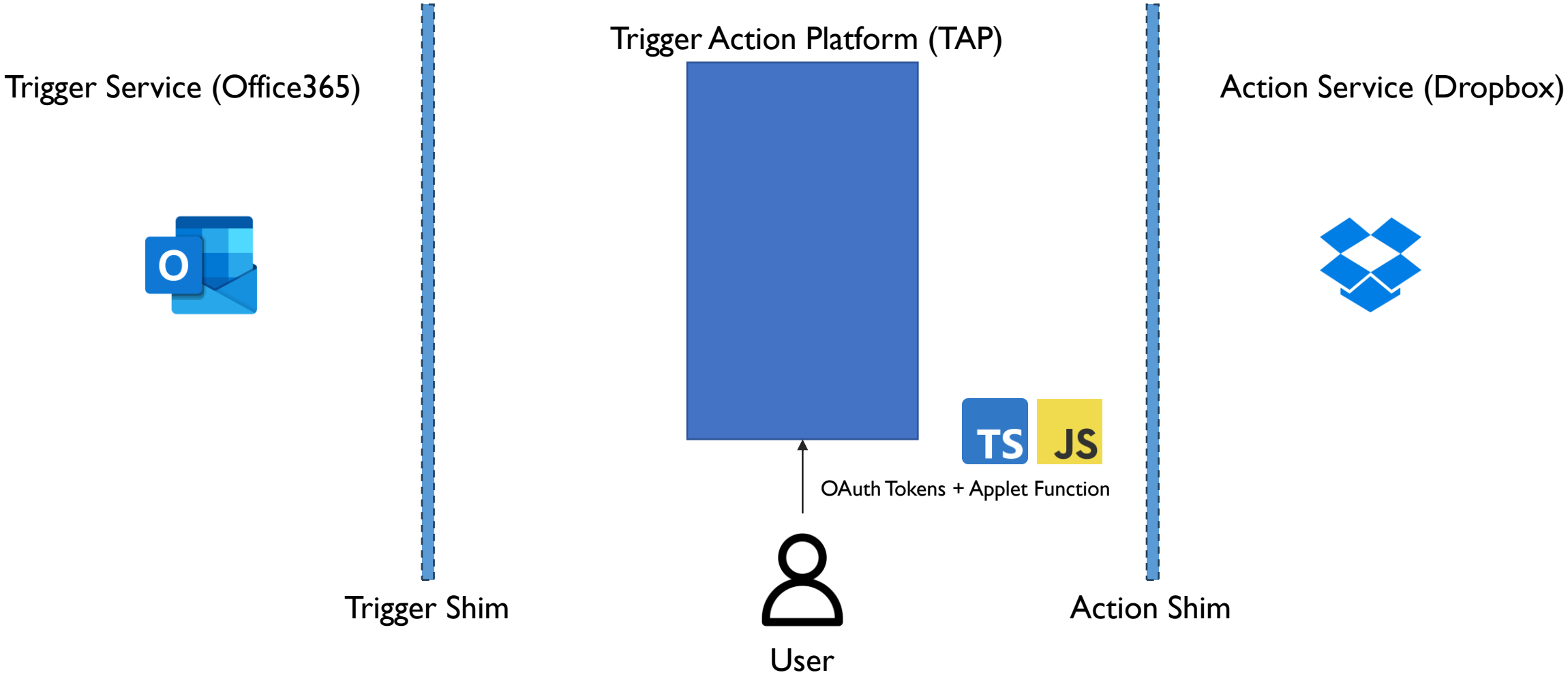
Action Service (Dropbox)

Trigger Shim

User

Action Shim

Trigger-Action Platforms



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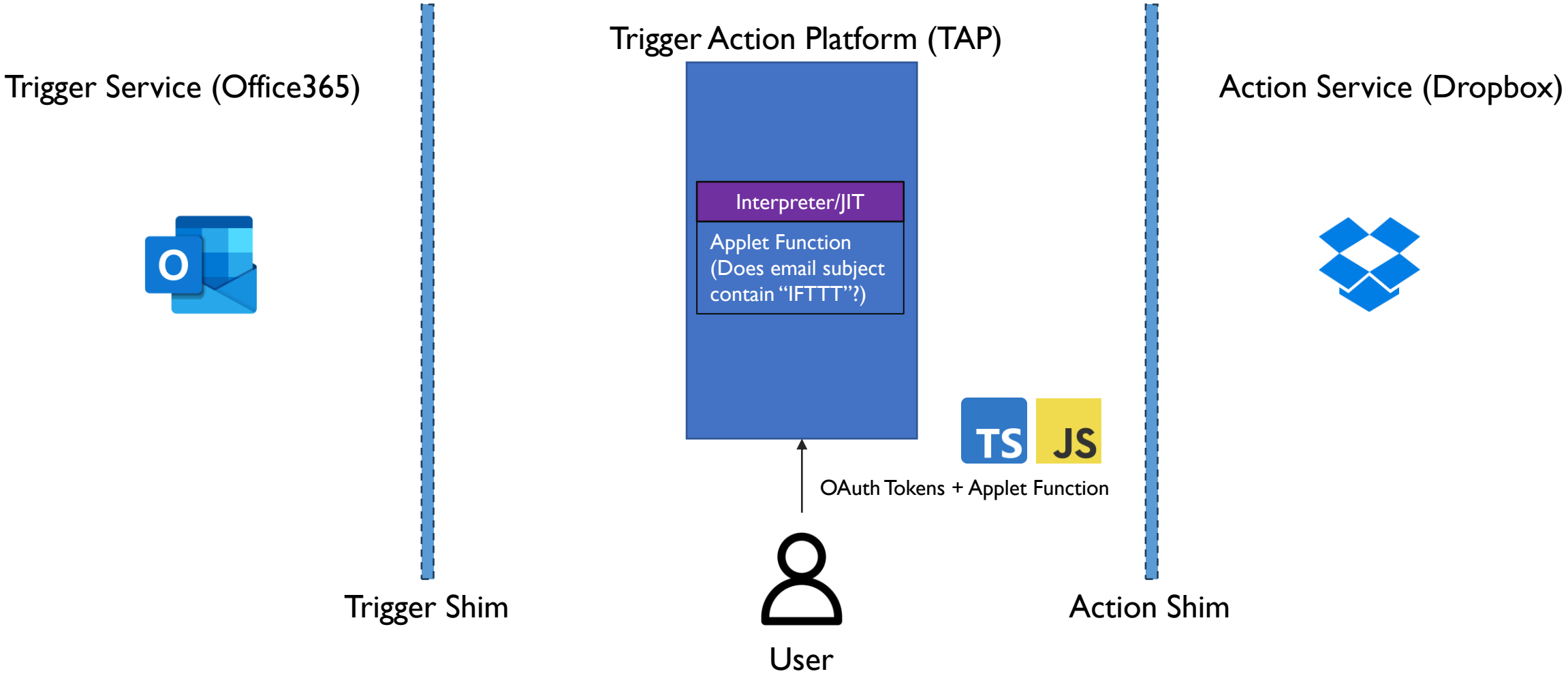

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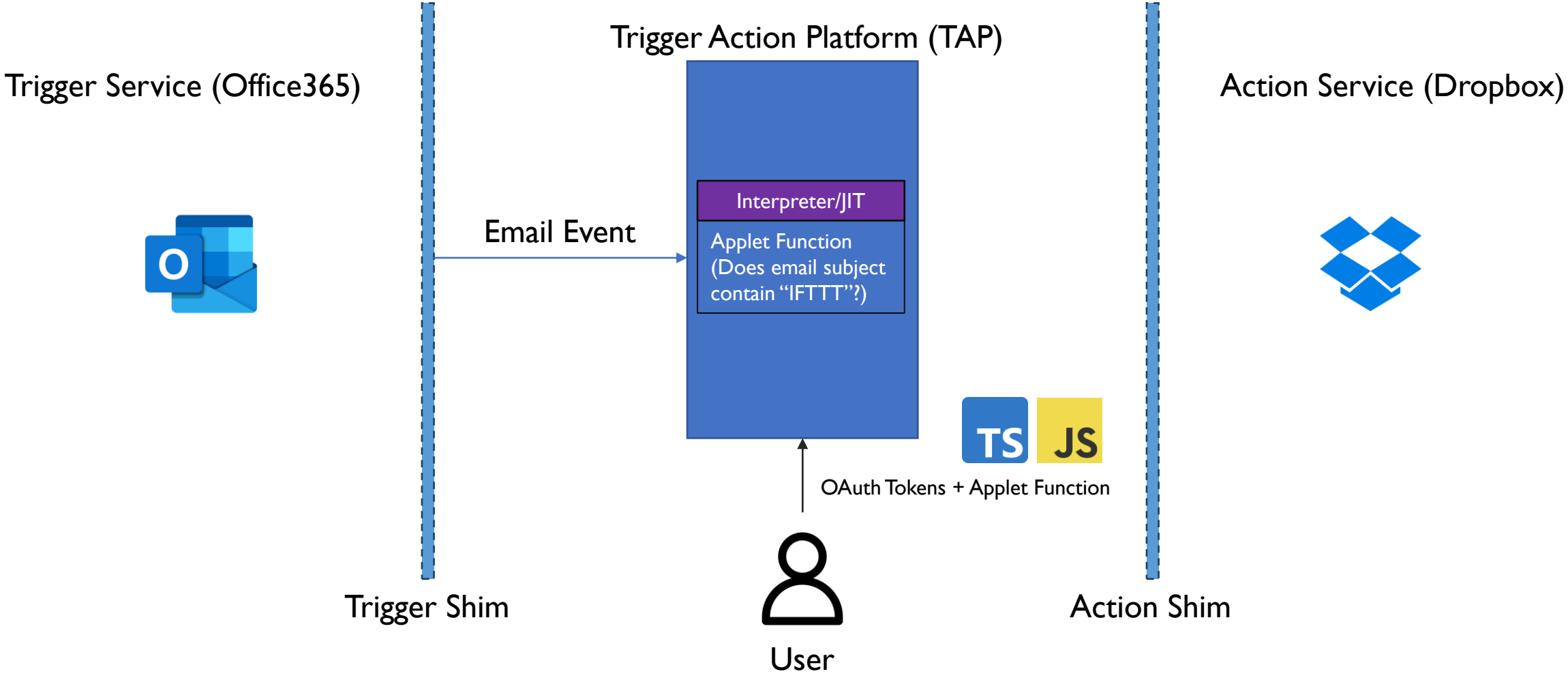

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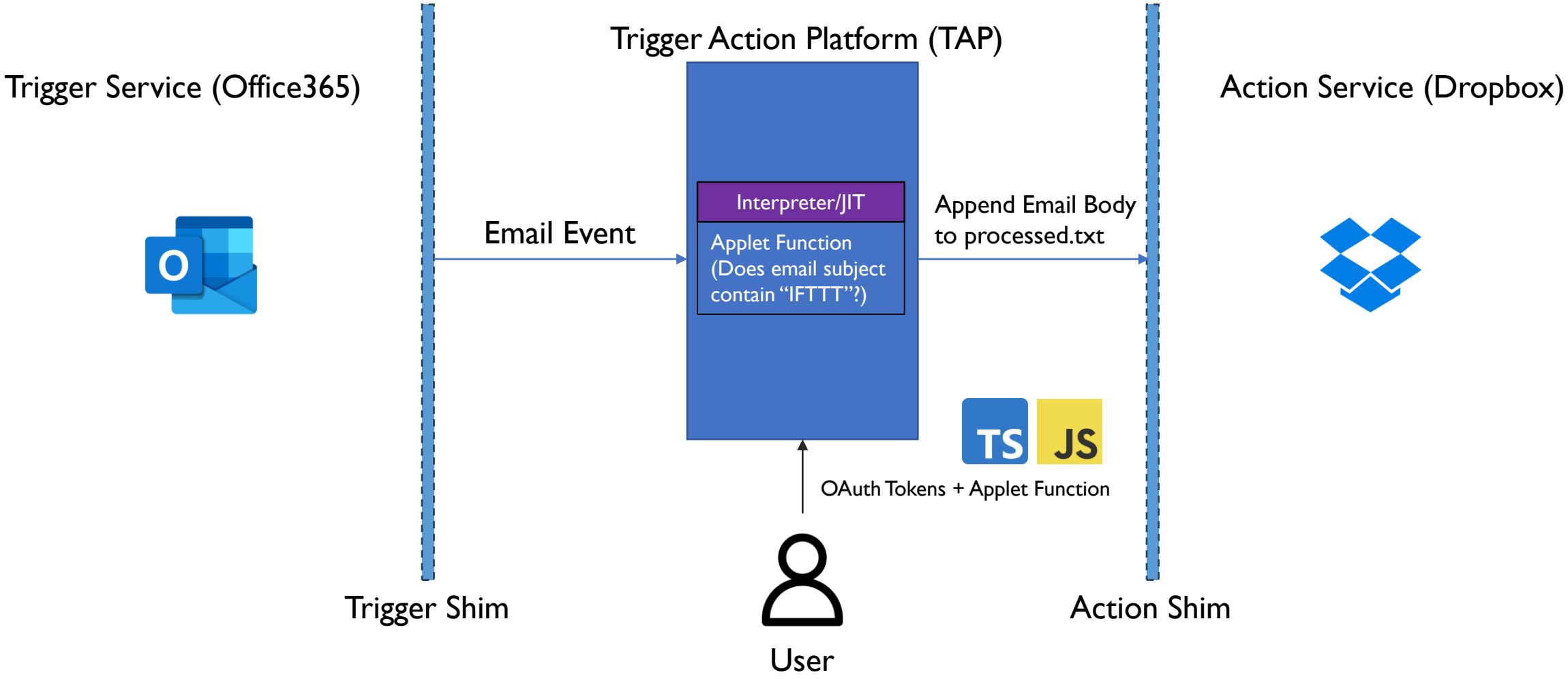

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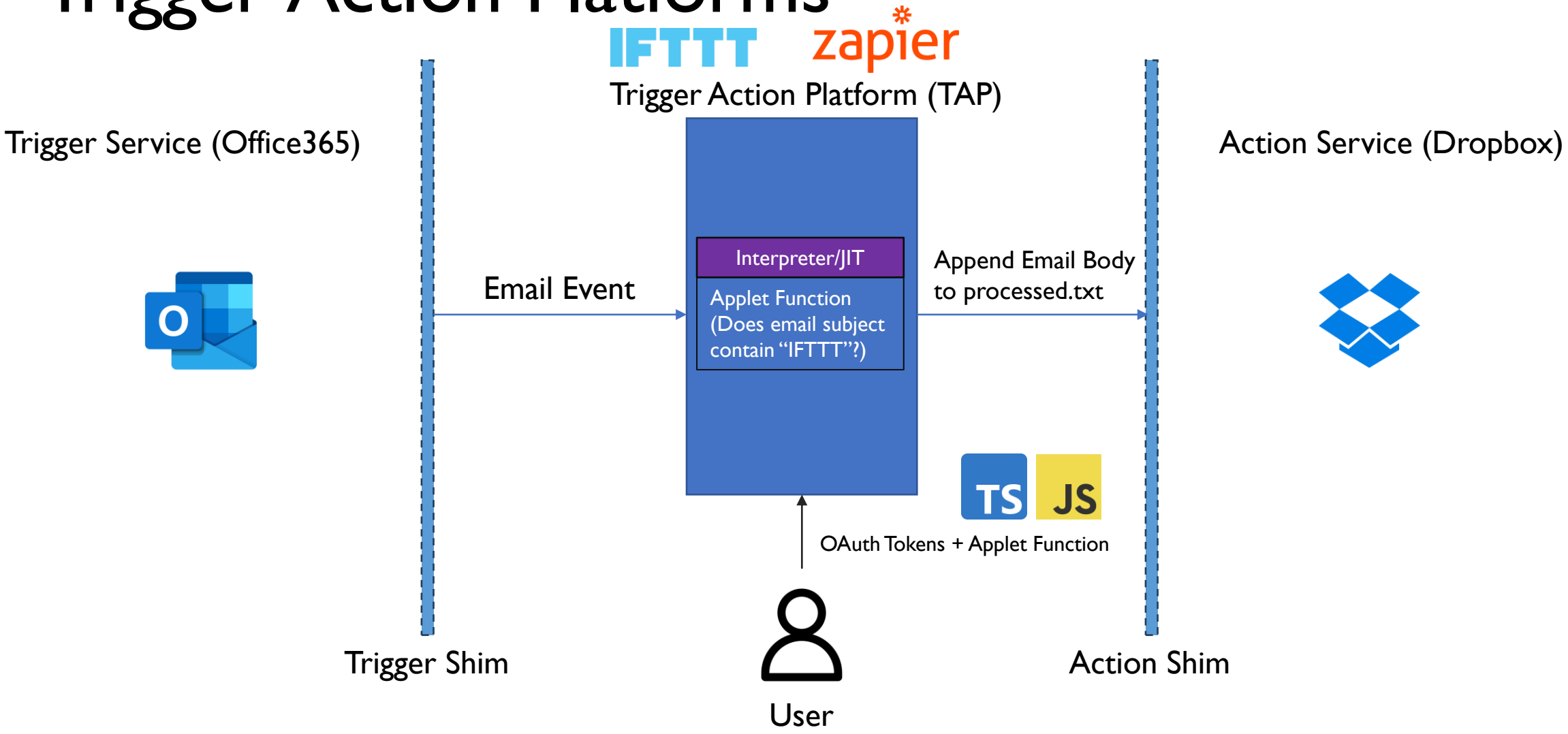

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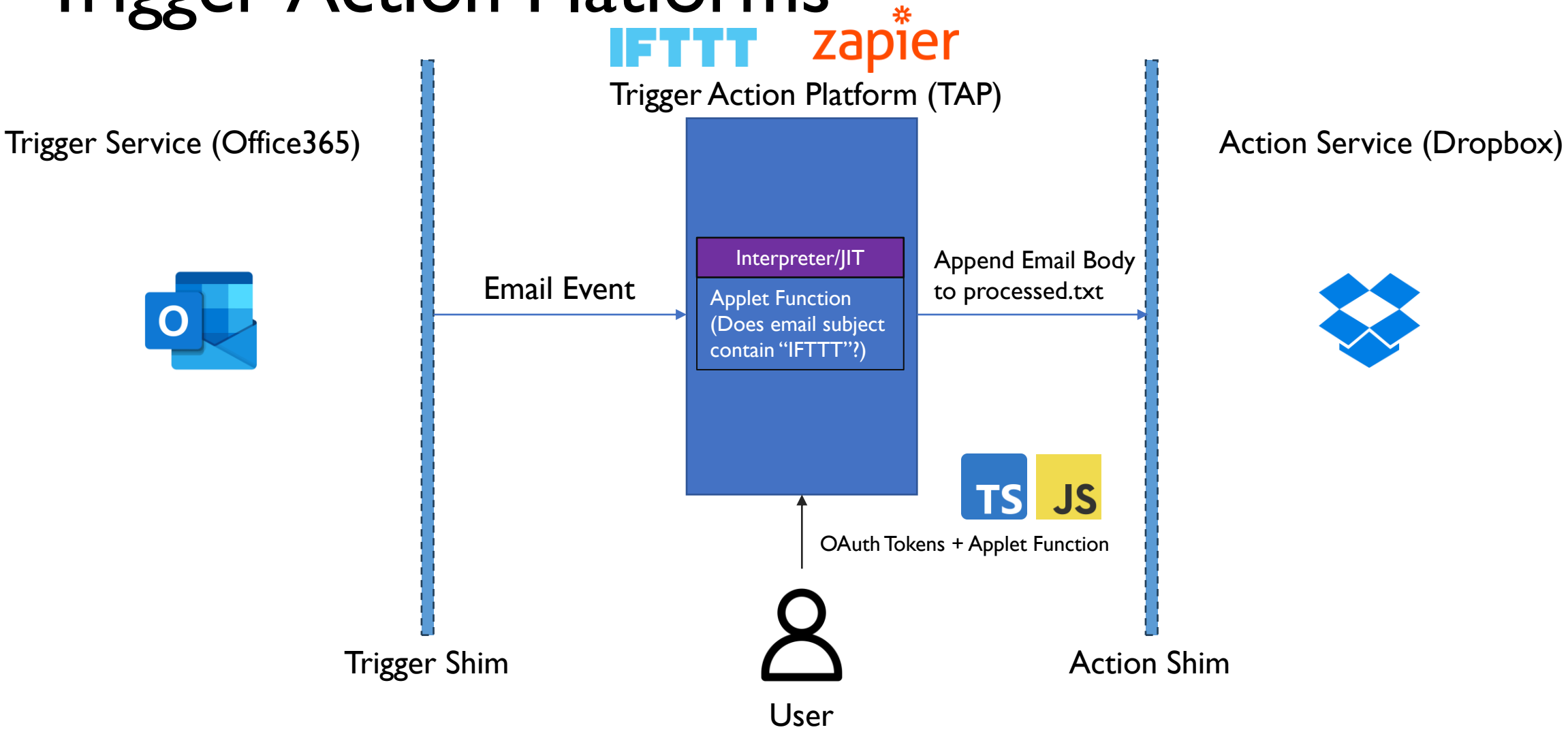
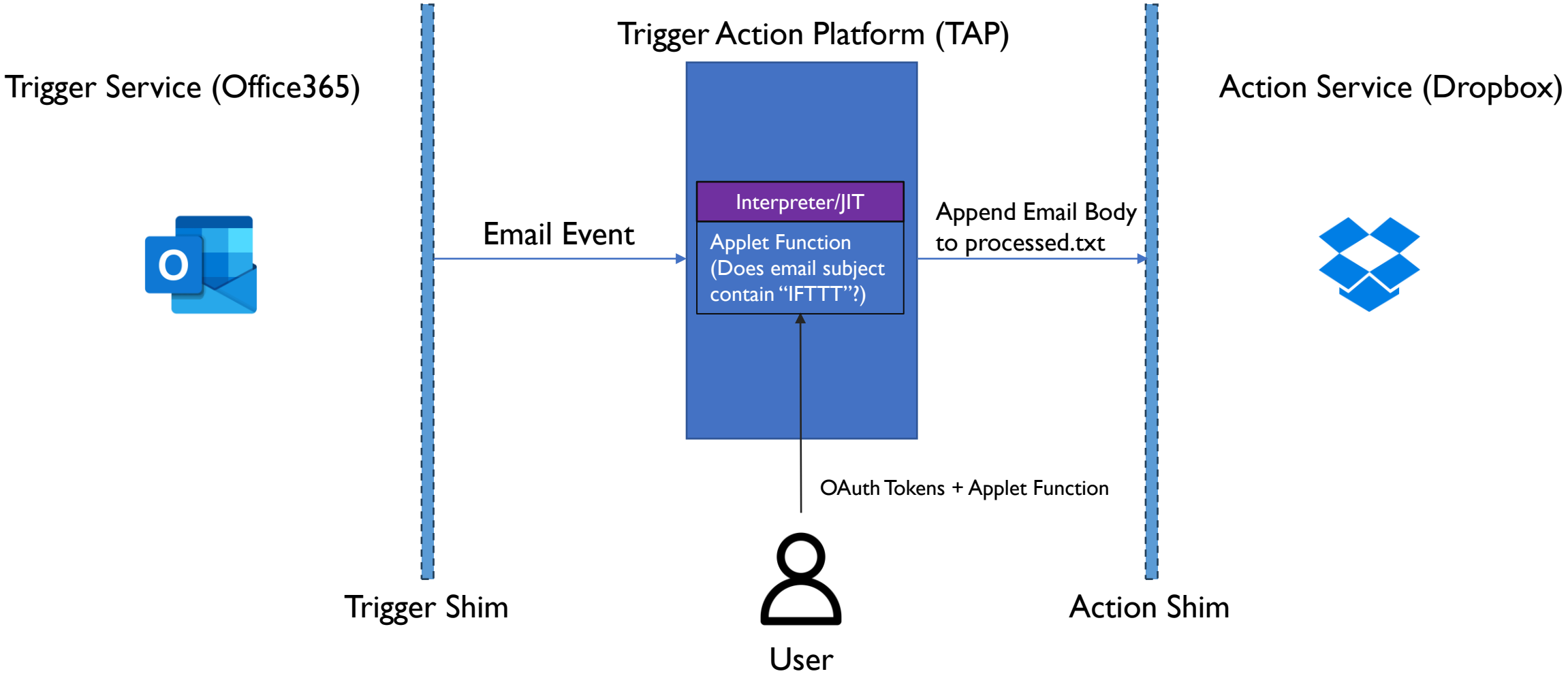


Millions of users must place complete trust in the correct operation of the Trigger Action Platform

Threat Model



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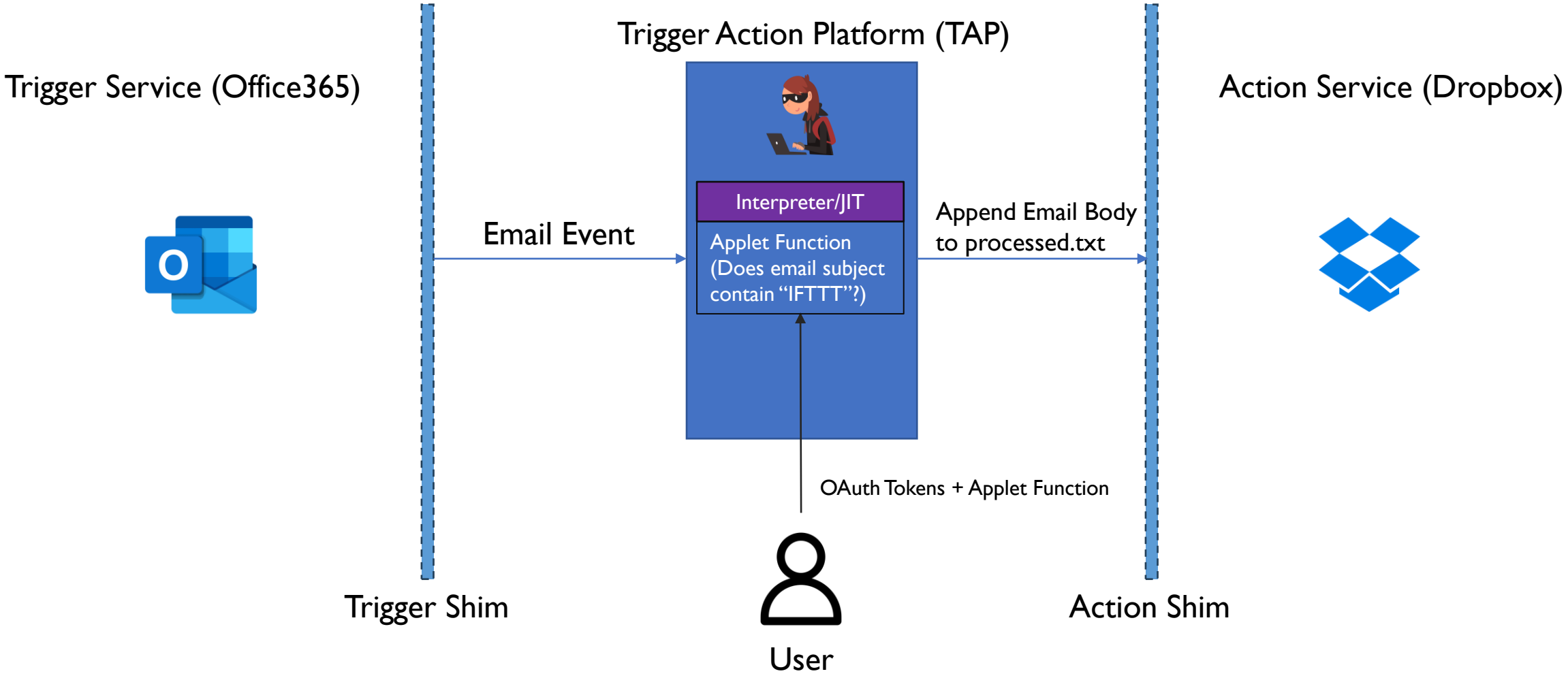

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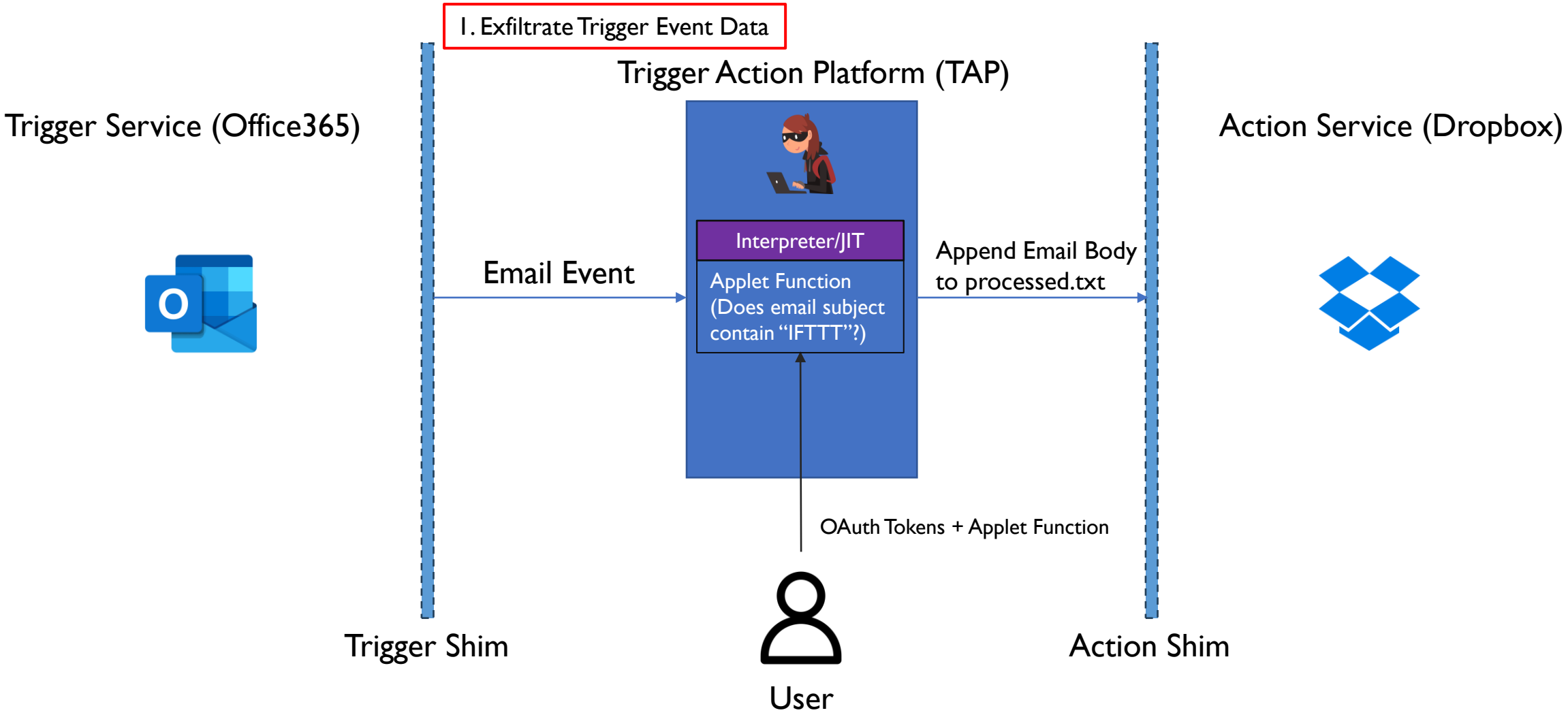

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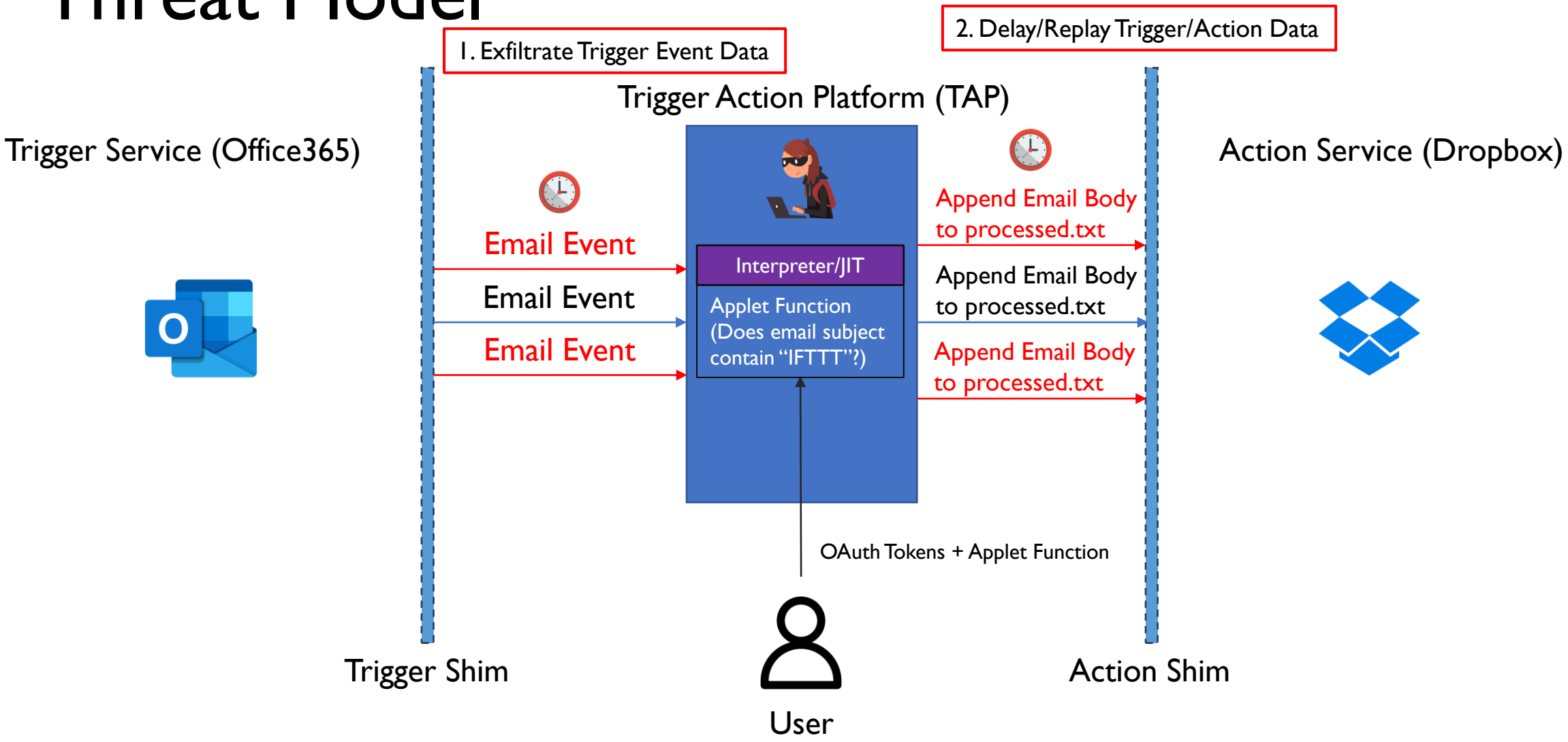

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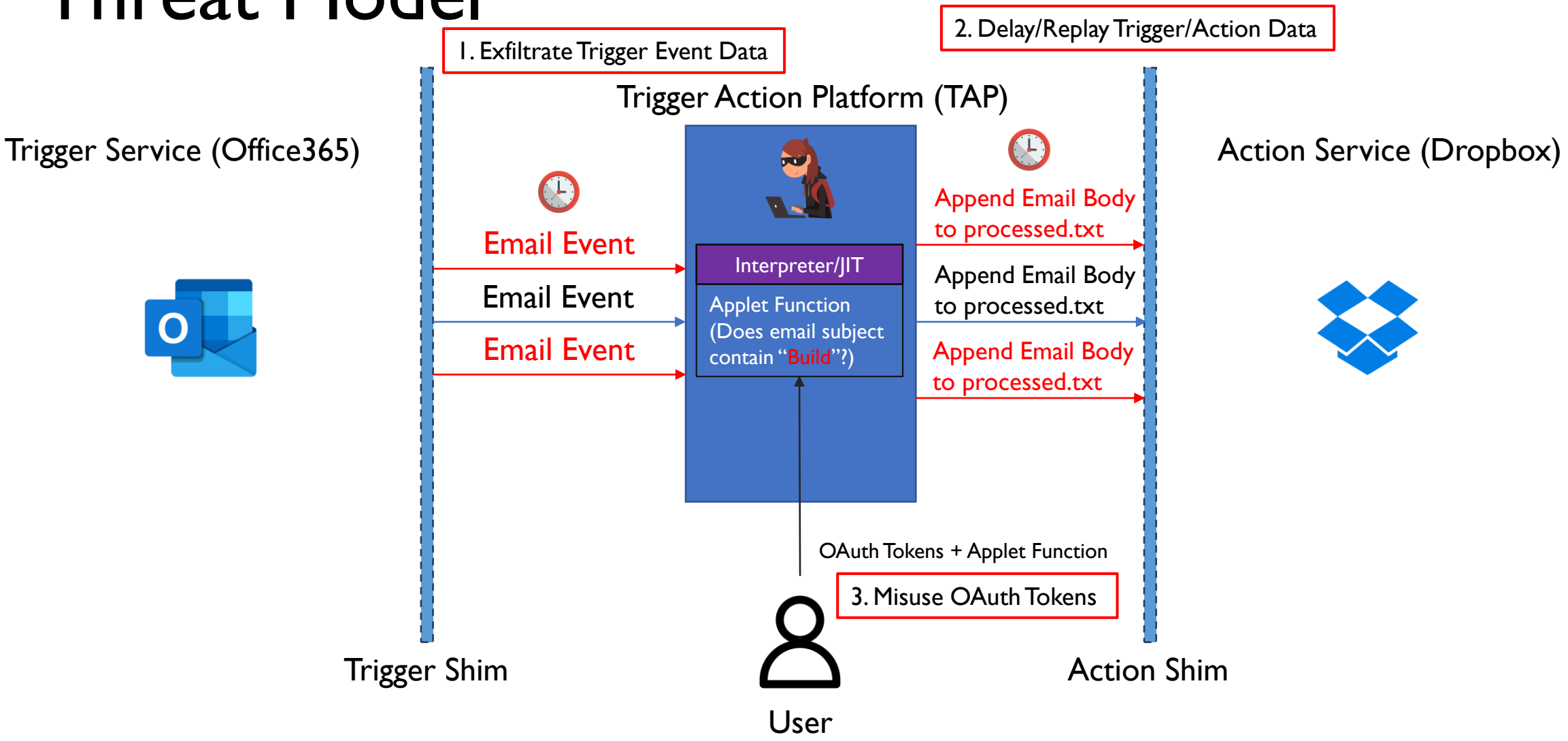

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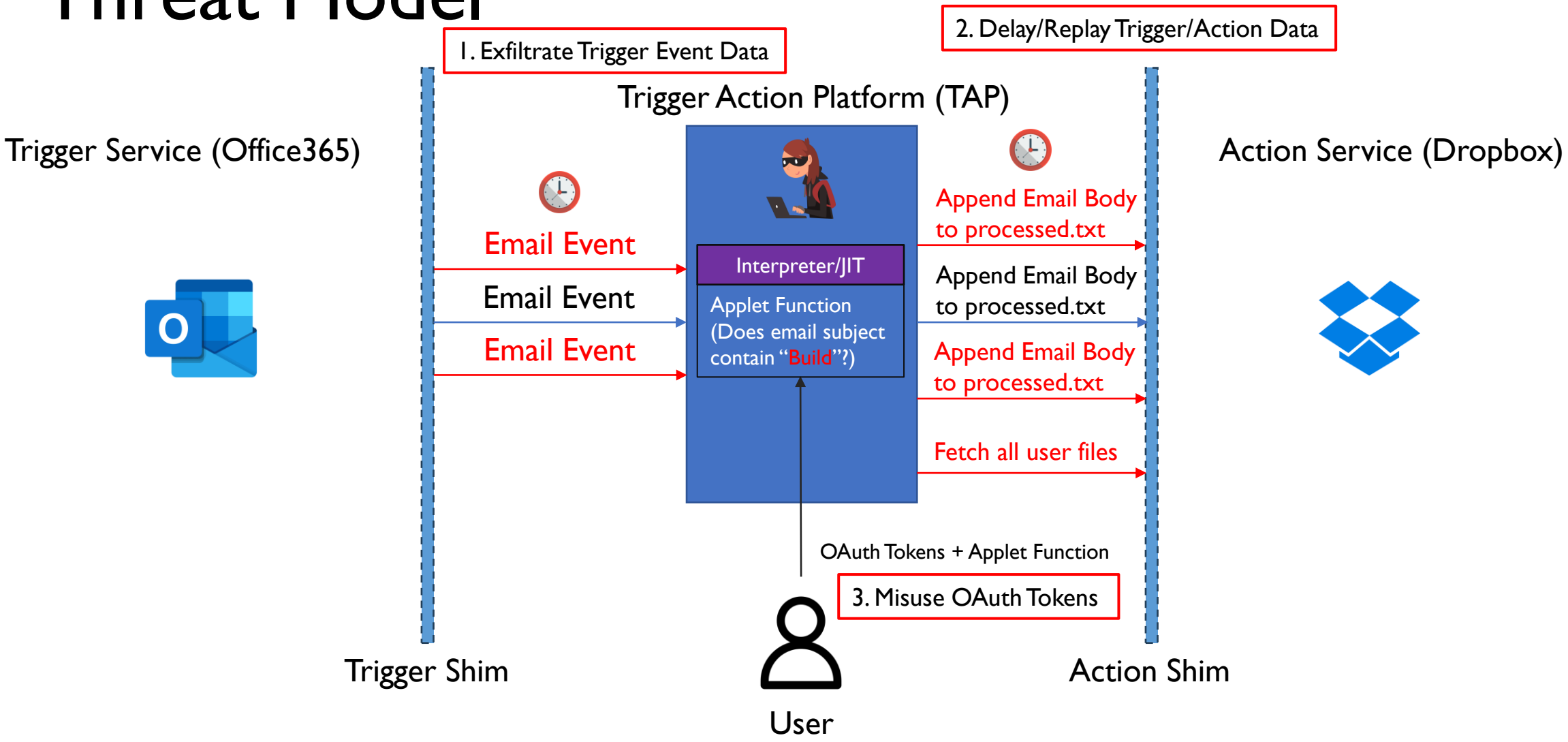

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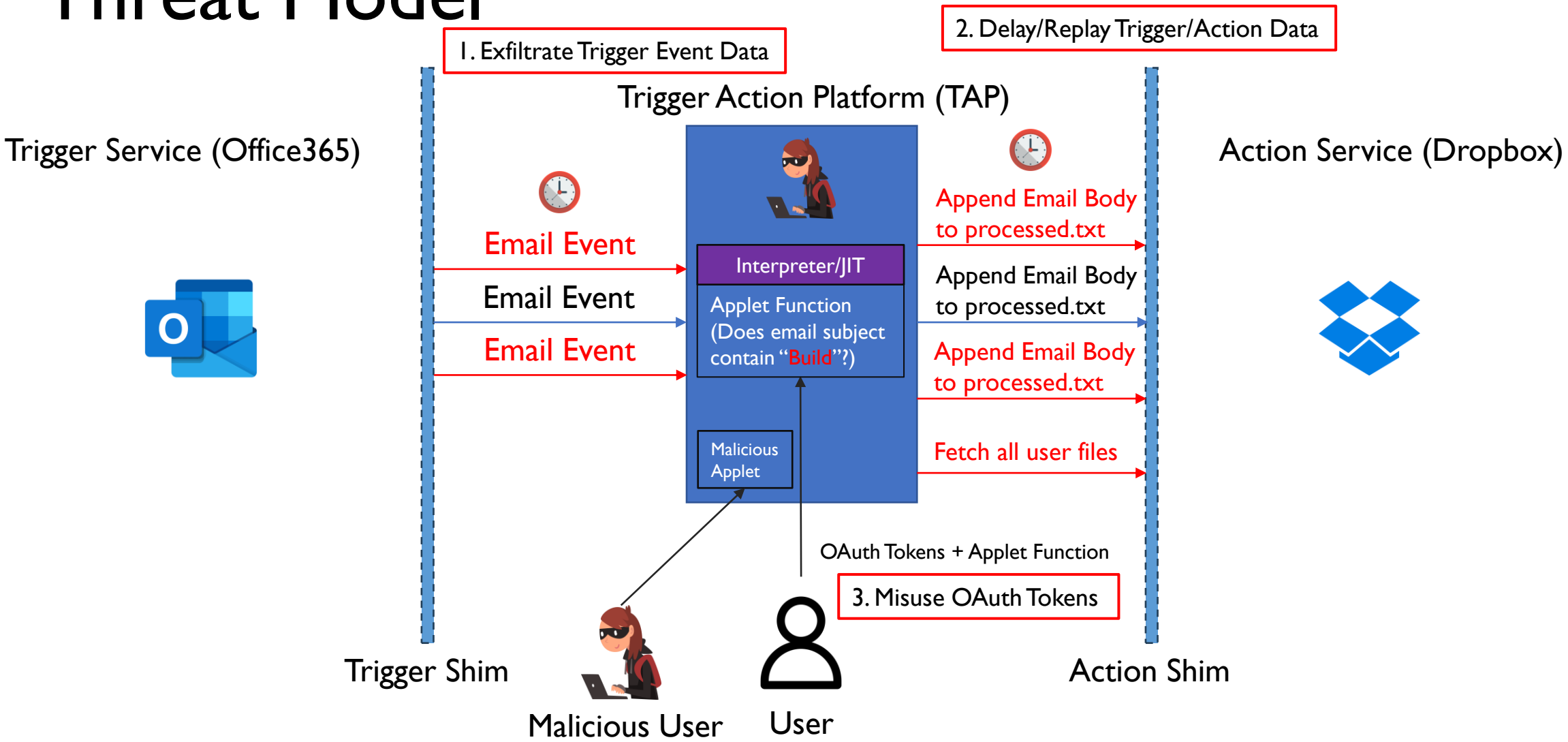

Can we design a TAP that can defend against these attacks?

Existing Approaches

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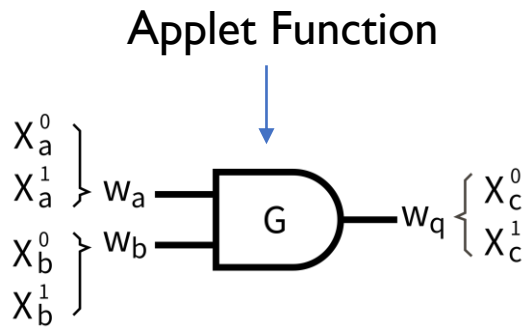
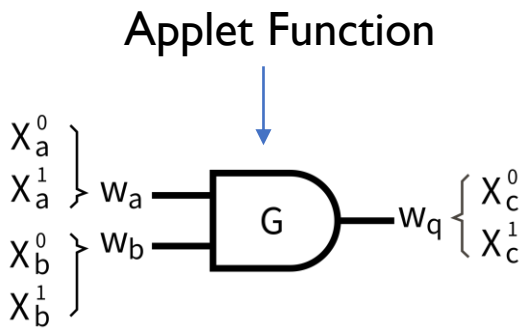


eTAP [S&P '21], Walnut [arXiv '20]

High Runtime Overhead and Restricted Programming Model

Existing Approaches



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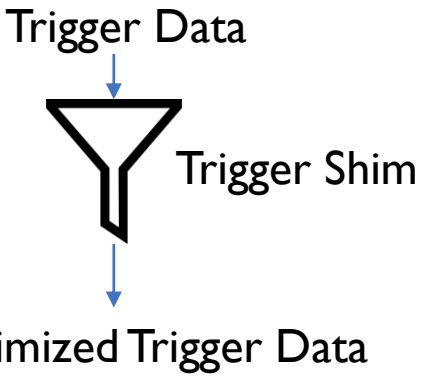

minTAP [USENIX Sec '22]

No Applet Execution Integrity

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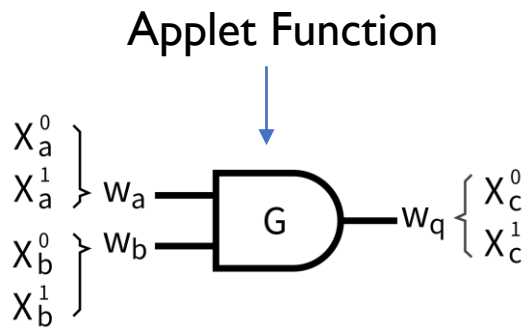

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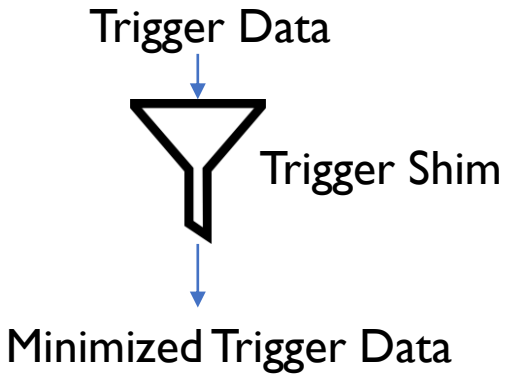

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No Applet Execution Integrity

Trigger Service → Action Service

DTAP [NDSS '18], OTAP[ESORICS '20]

No Support for Applets

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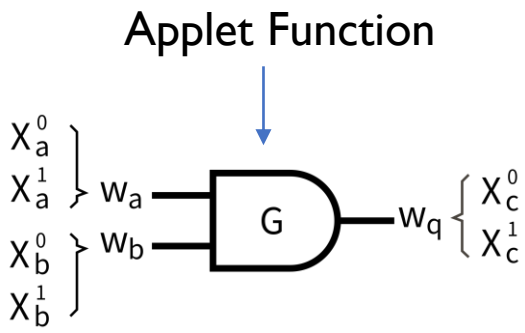

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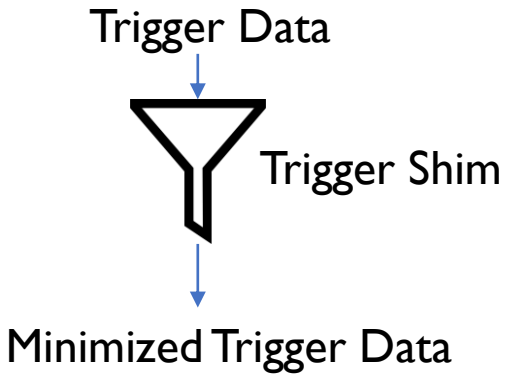

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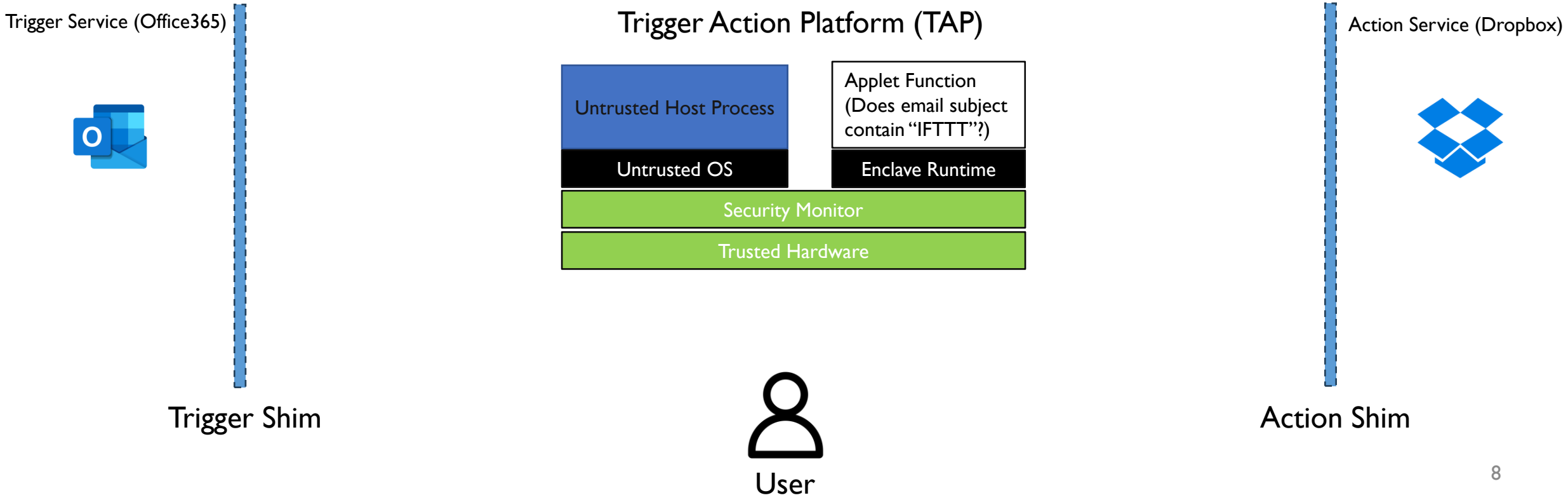
Can we design a TAP that can defend against these attacks along with high performance and functionality?

Our Approach: TAPDance

Insight: TAPs have a restricted execution model; Run Applet inside a RISC-V Keystone hardware enclave



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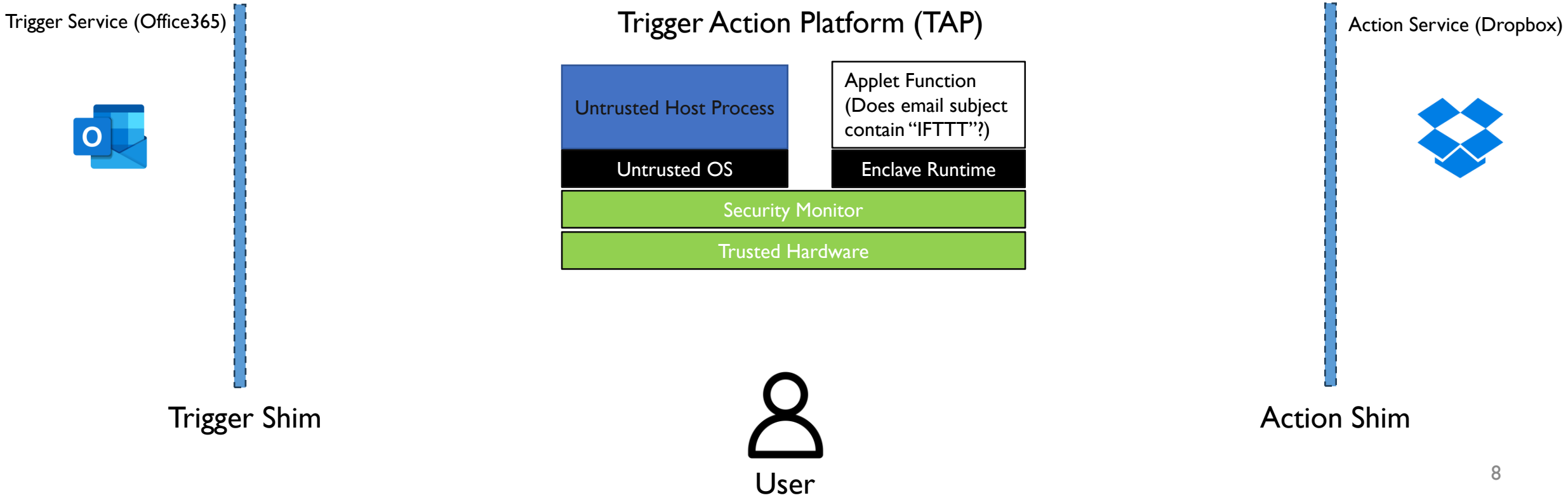
Keystone Security Monitor provides customizability



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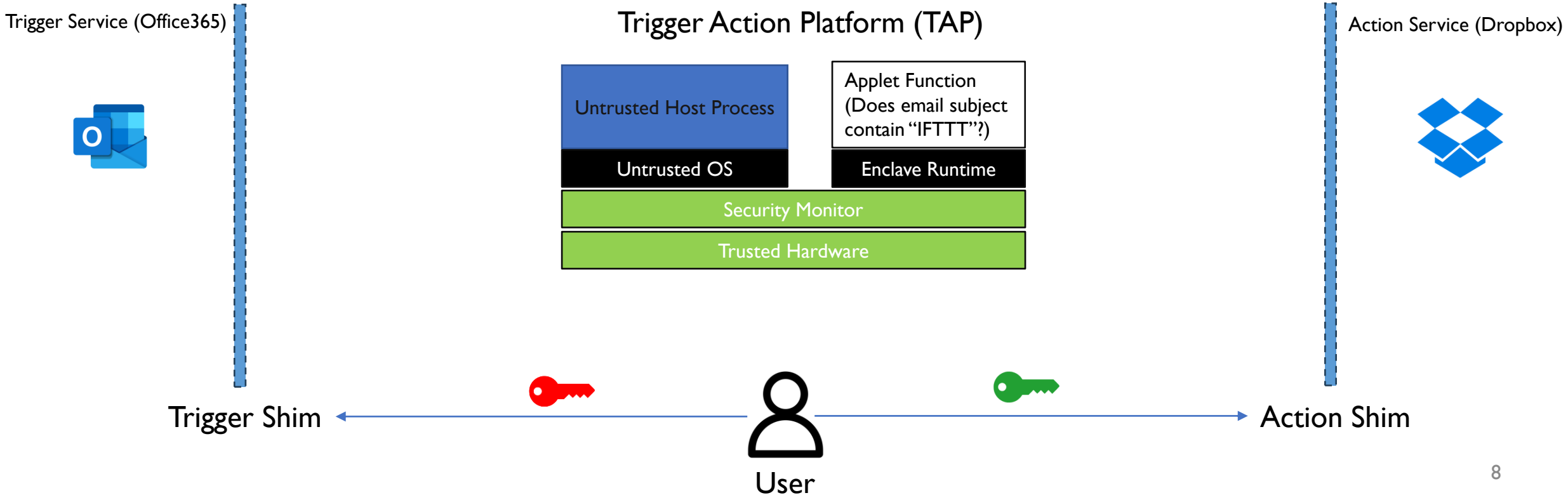

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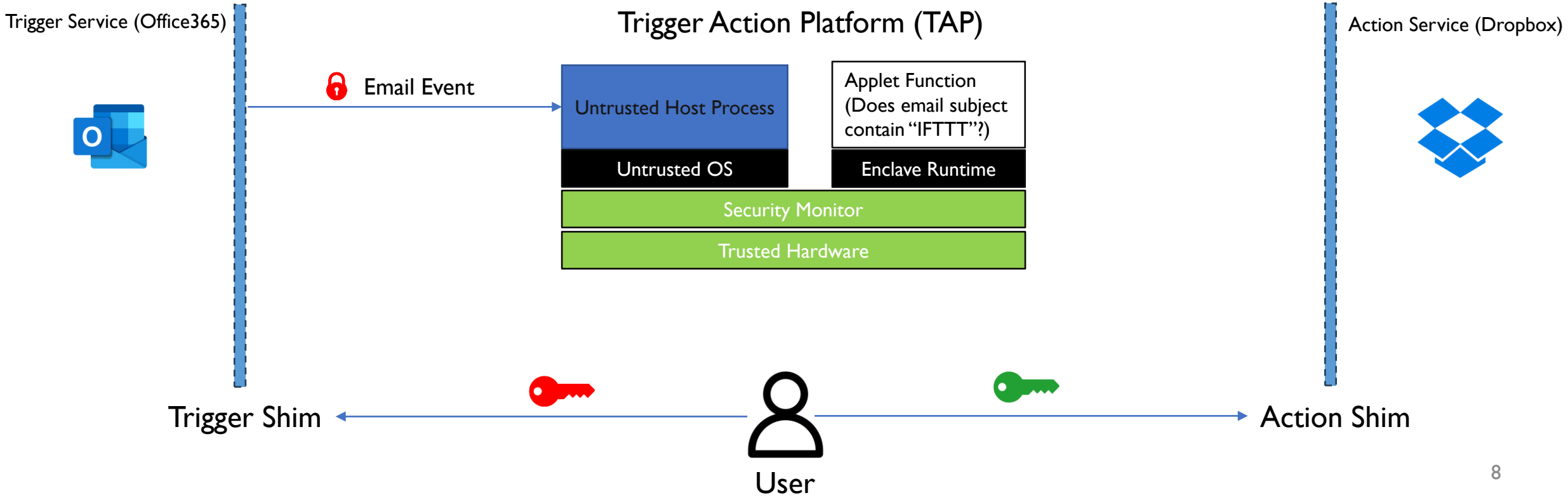

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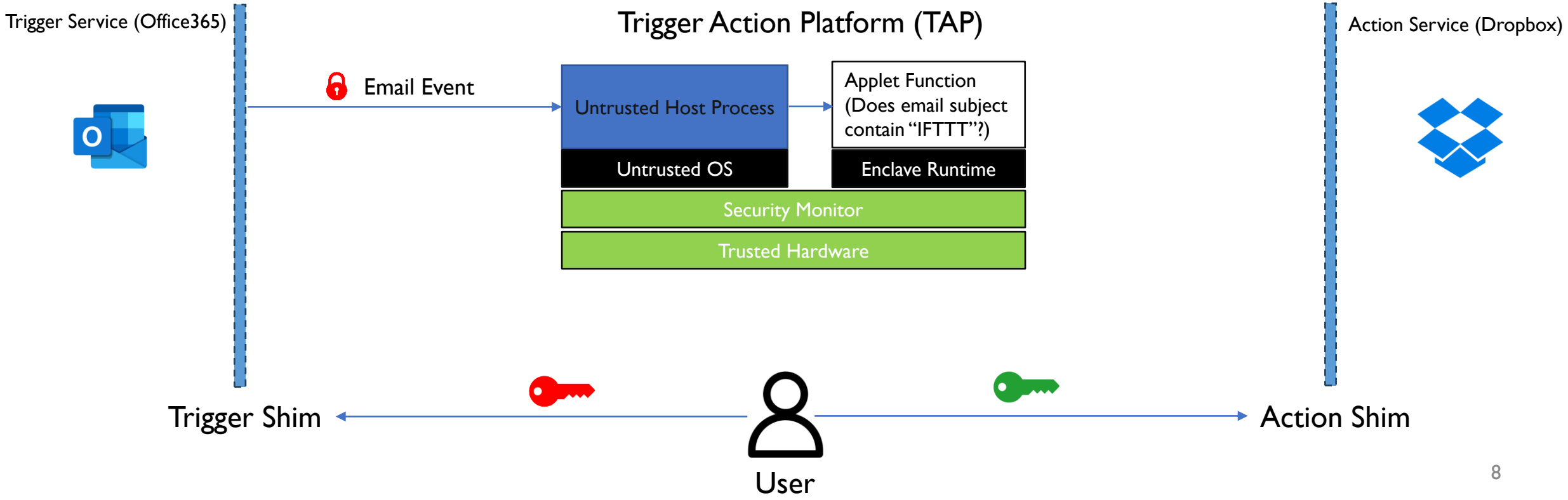

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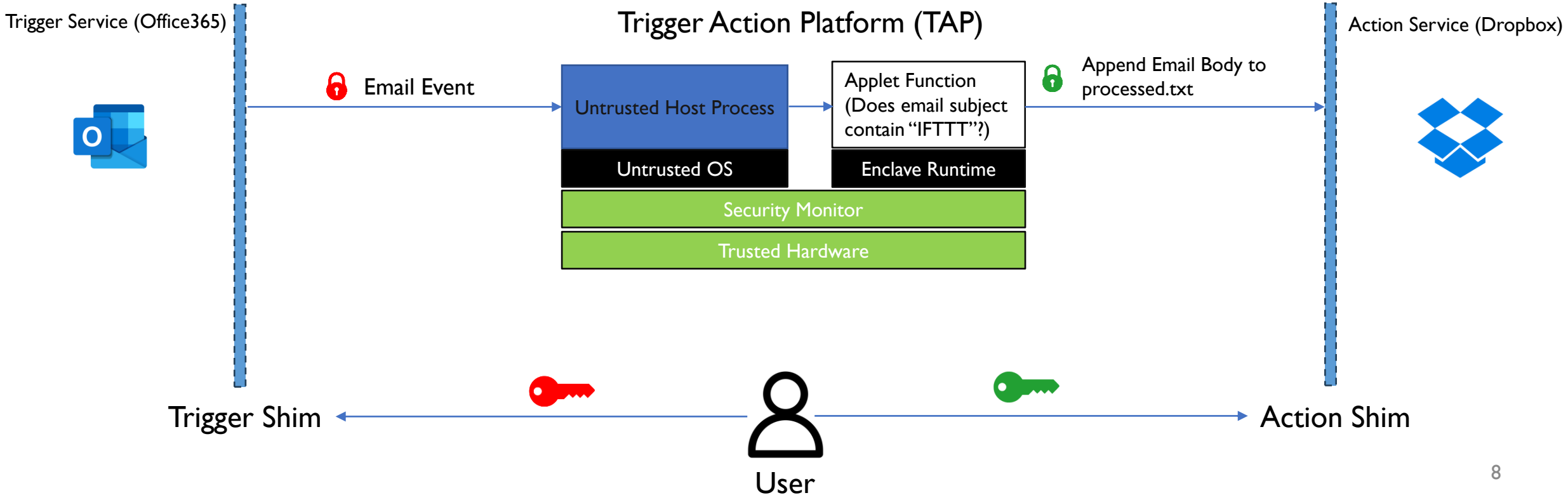
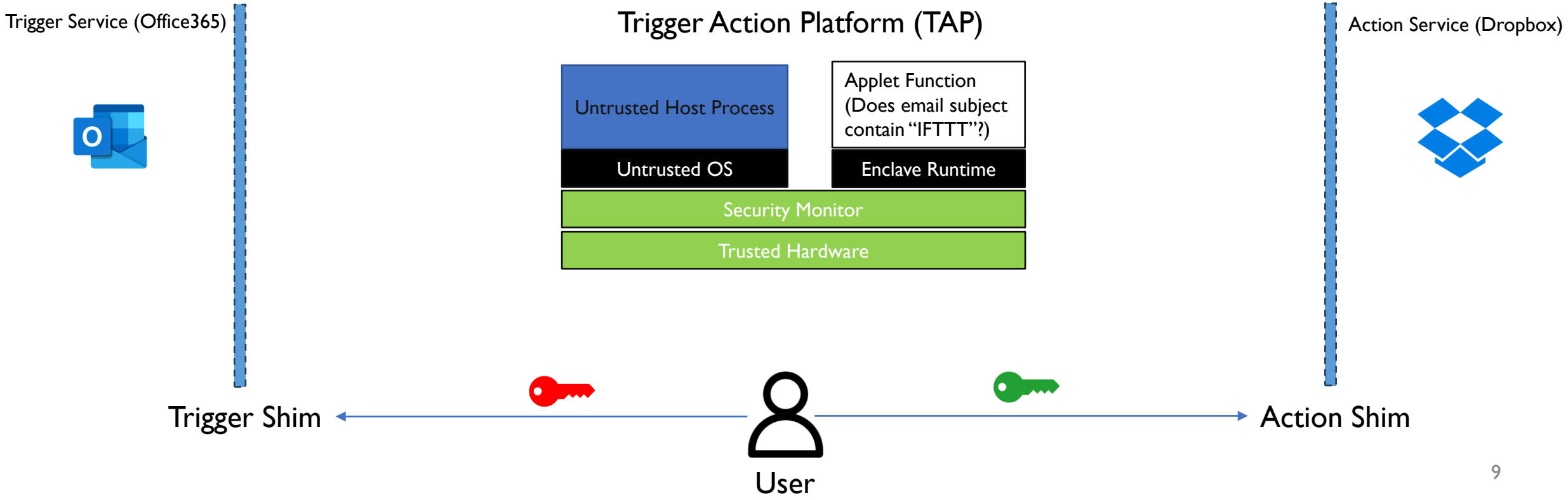


Challenge 1: Freshness and Replay Protection

Problem: Freshness and Replay protection are not primitives offered by Enclaves



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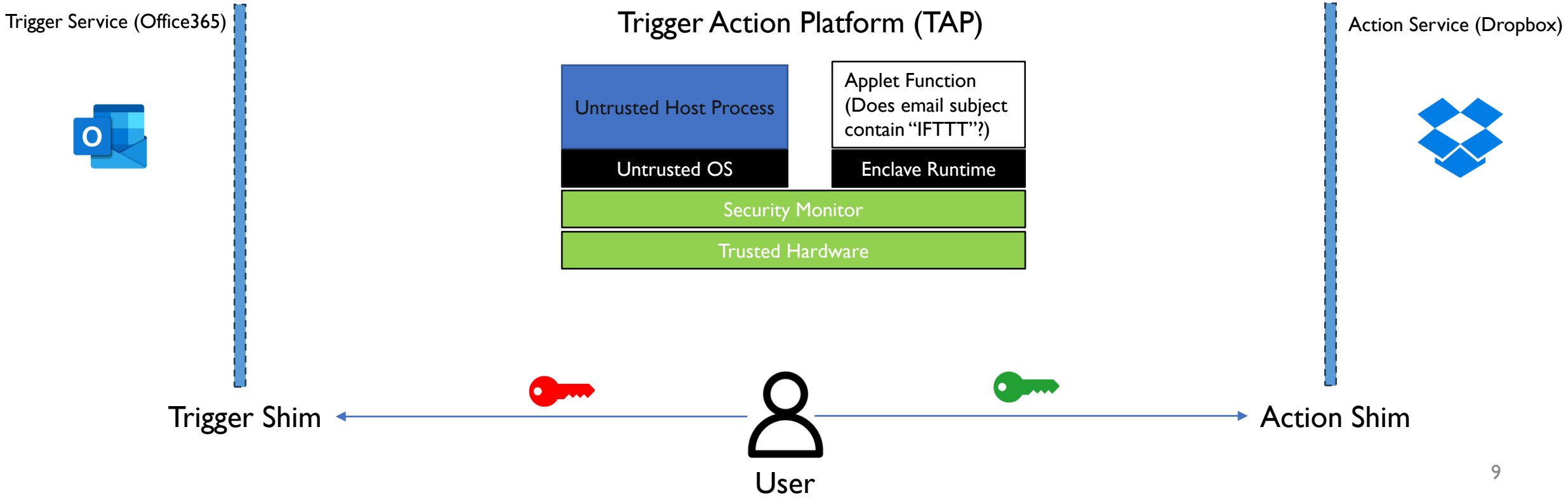
Idea 1: Get Trigger Shim to associate and tag event data with nonce maintained by Security Monitor



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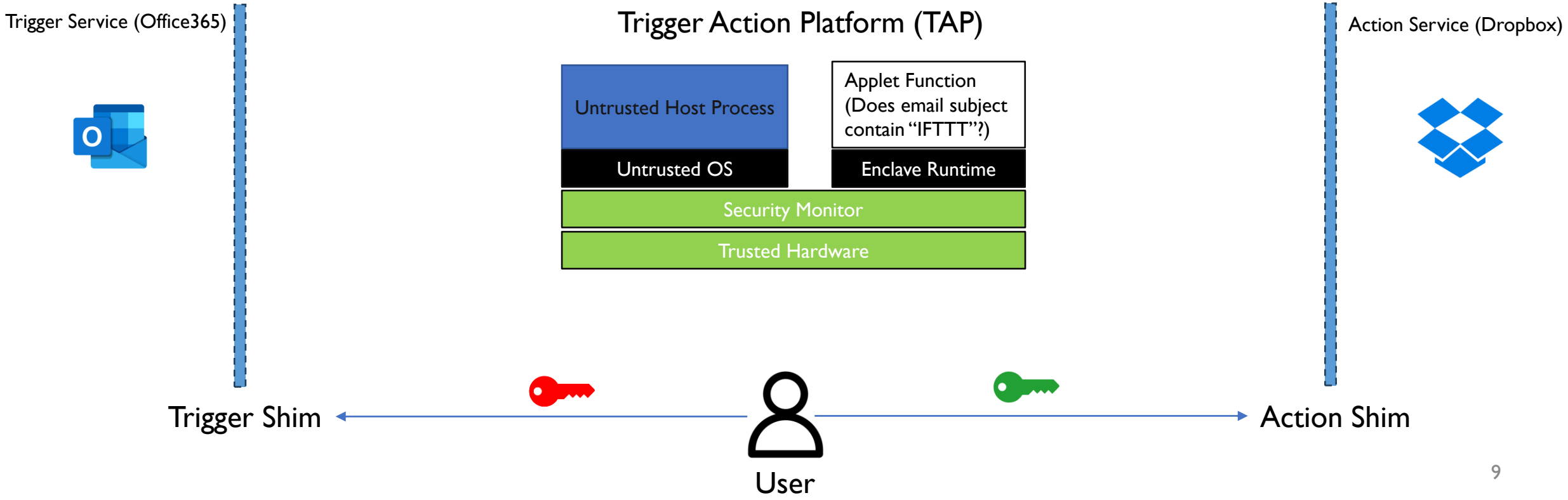
Idea 2: Security Monitor provides a secure time service to the applet enclave



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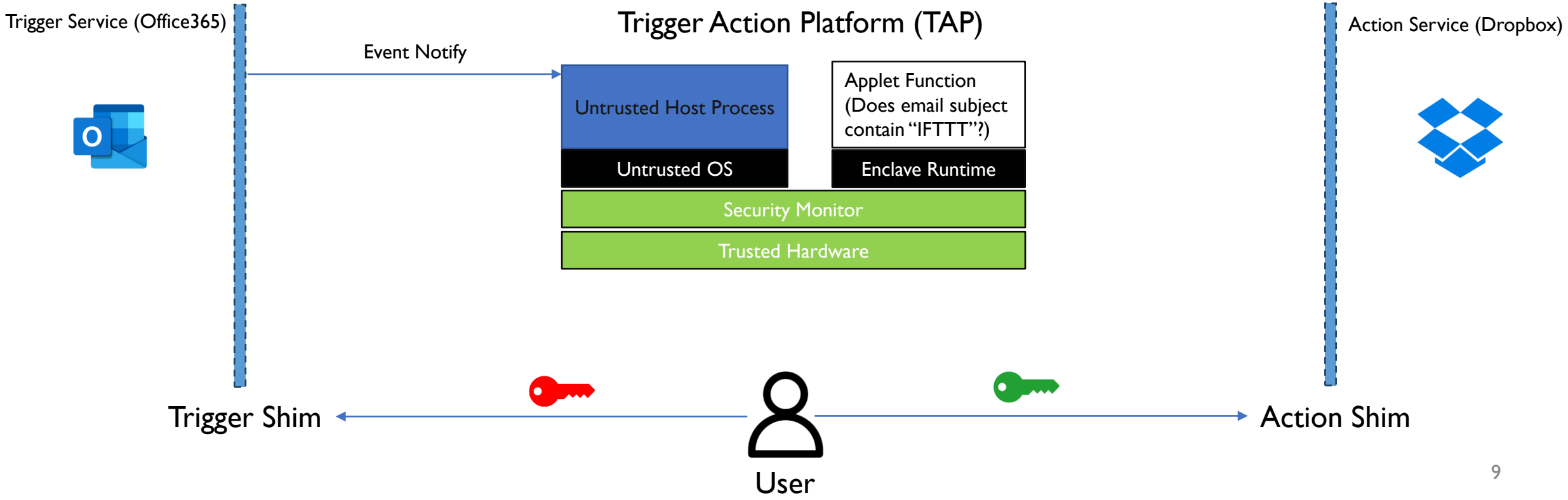

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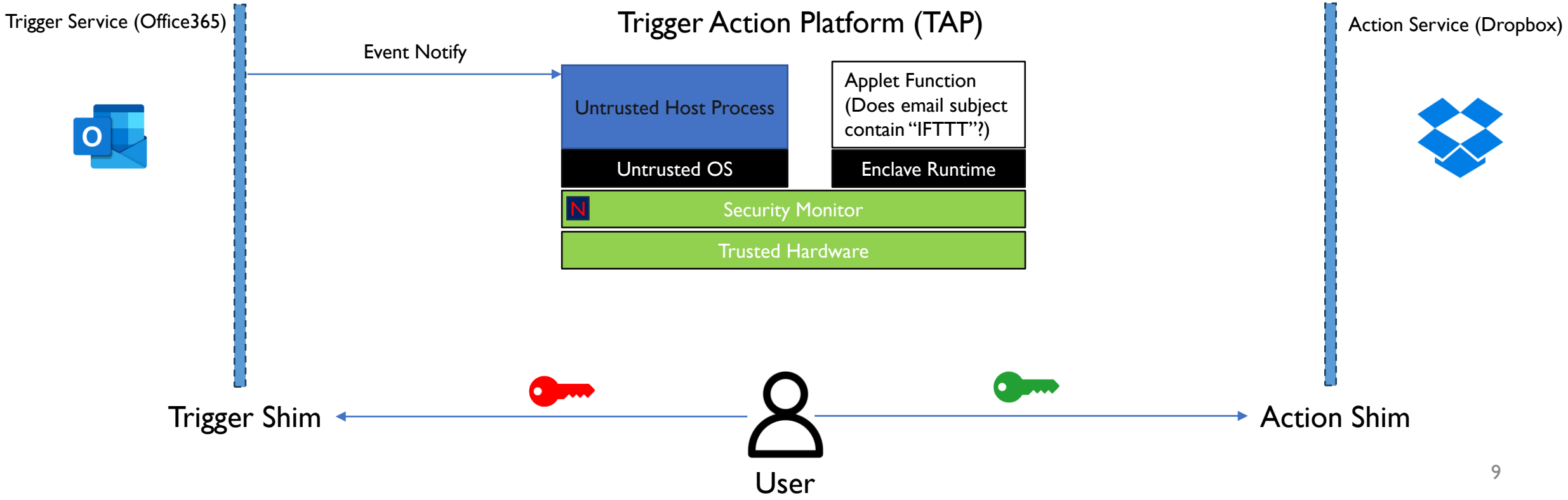

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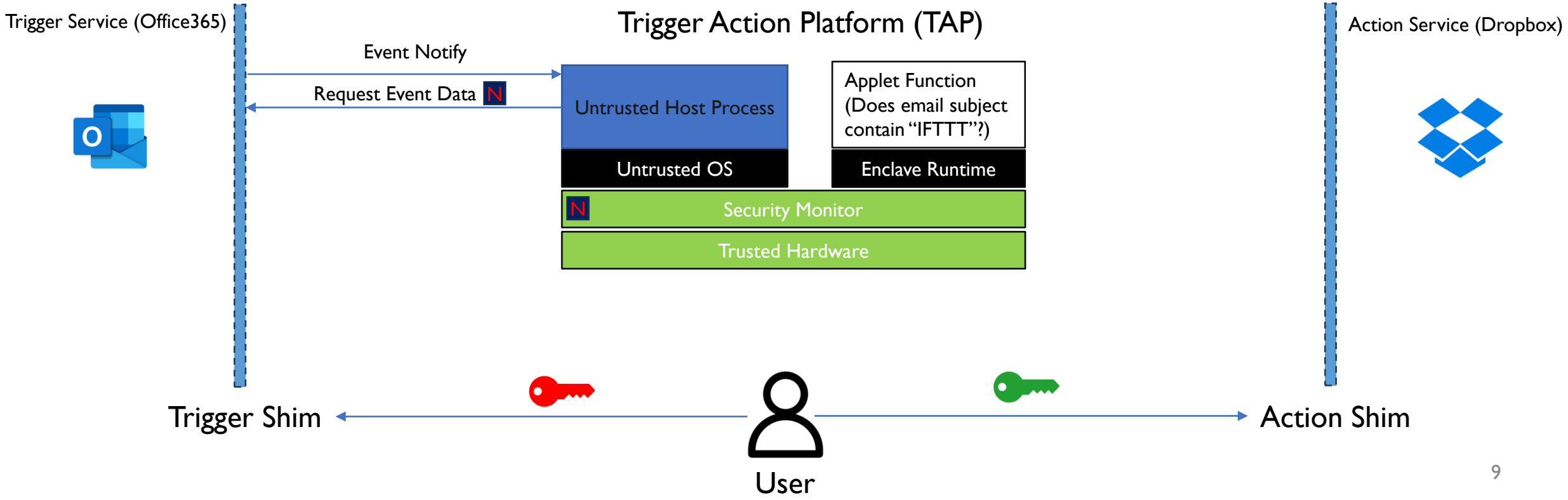

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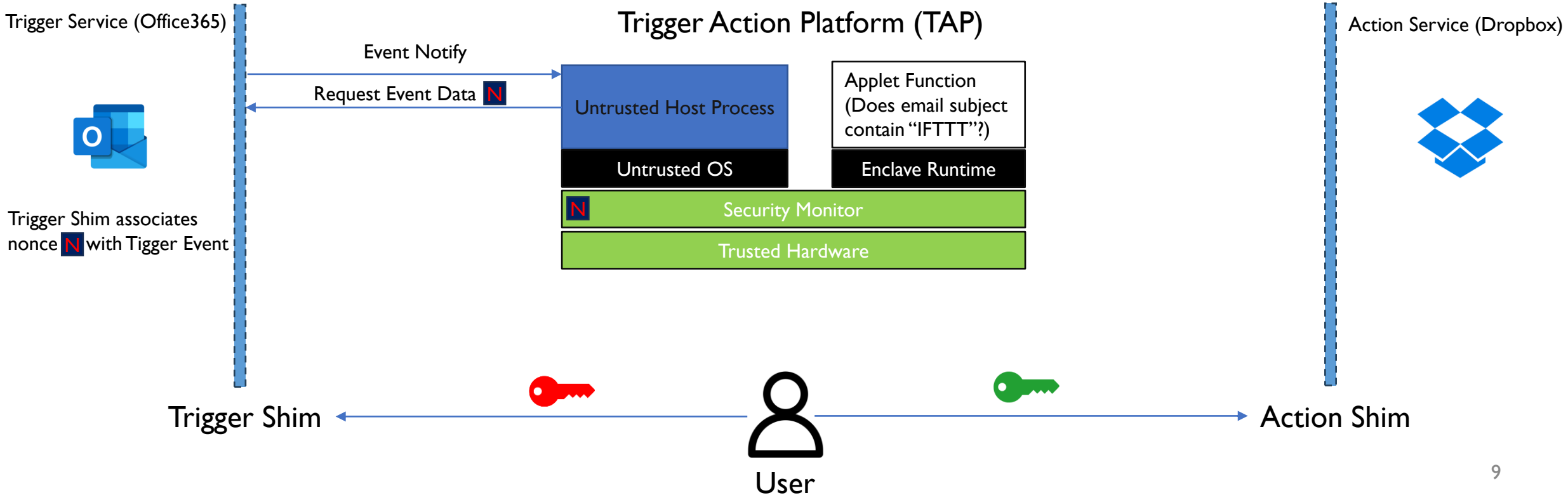

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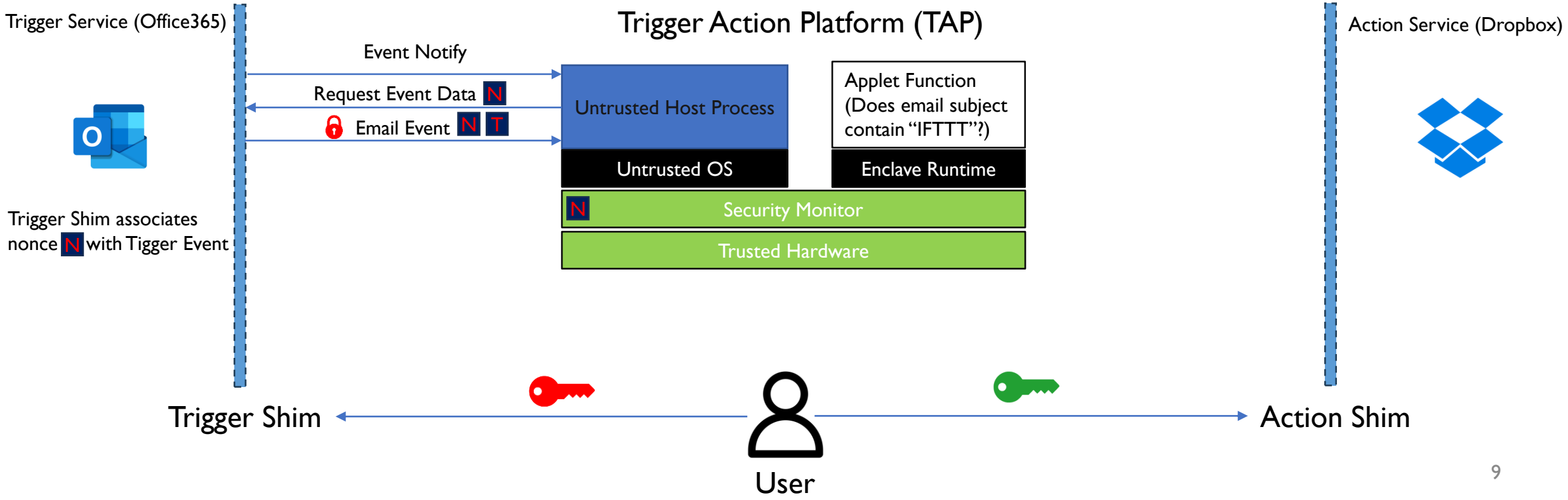

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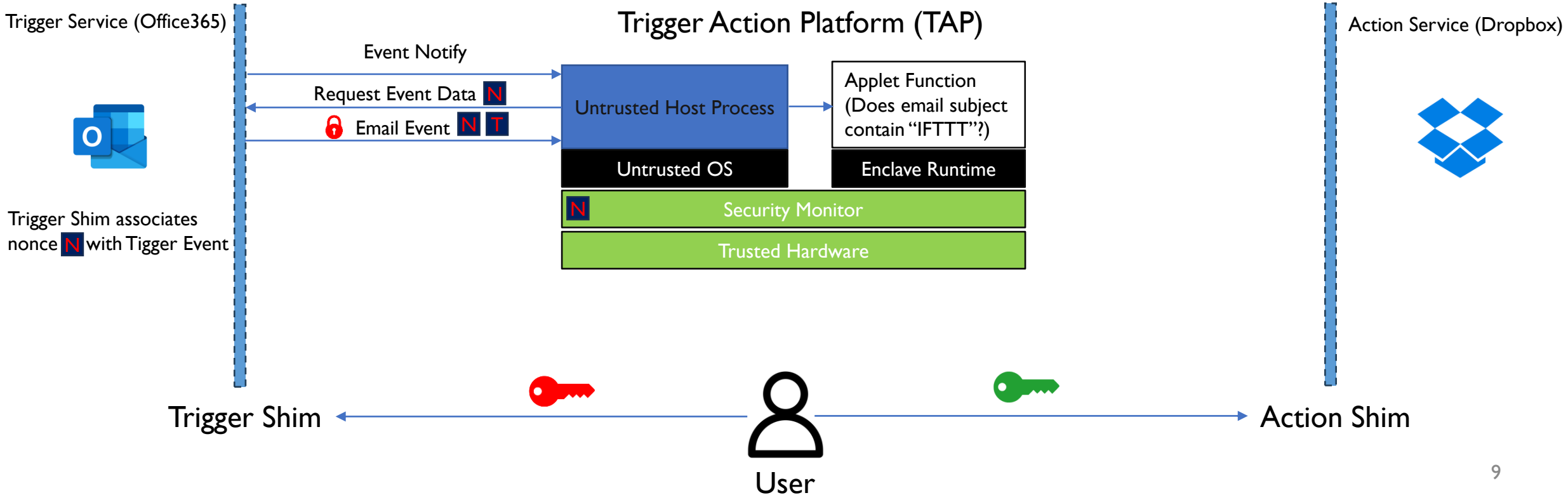

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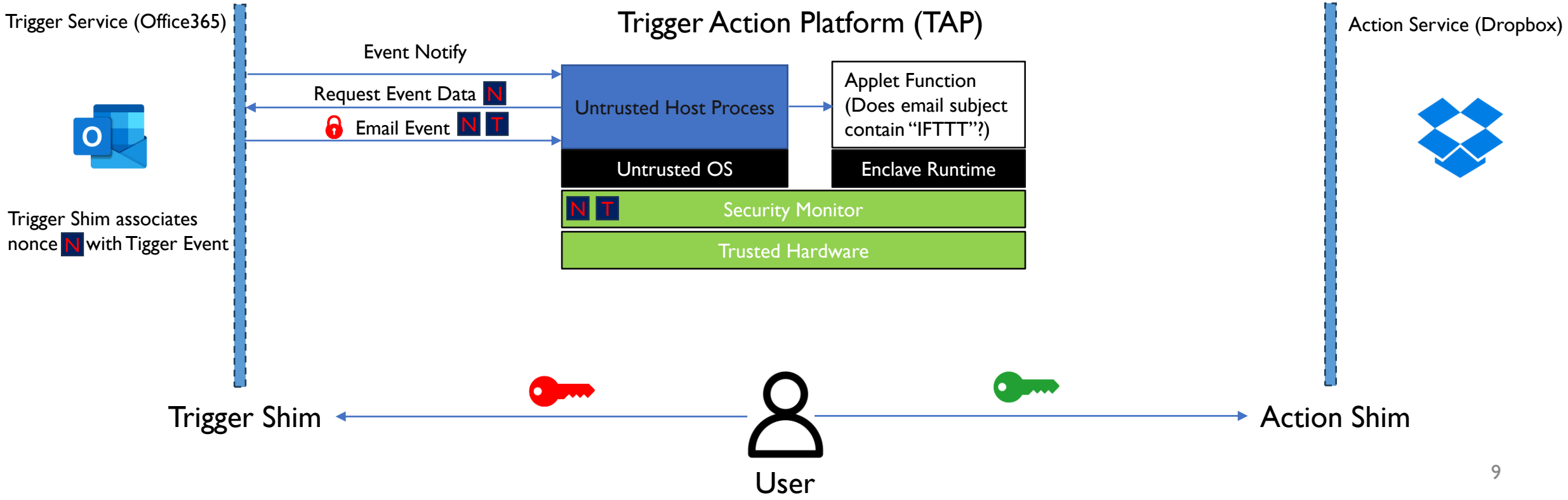

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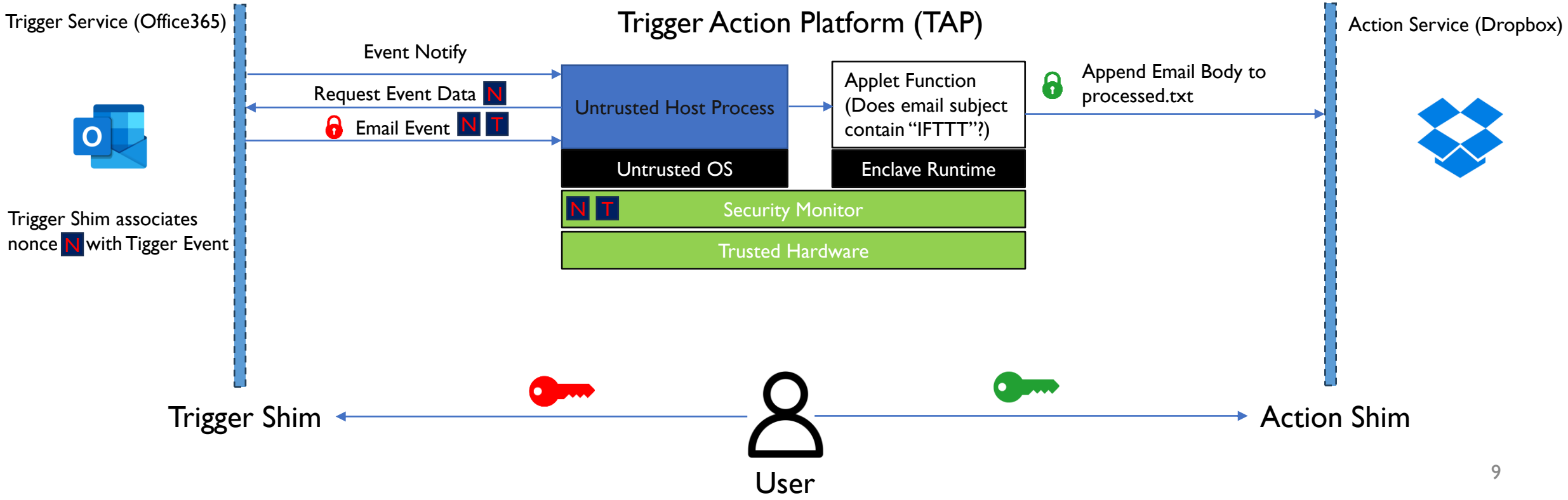
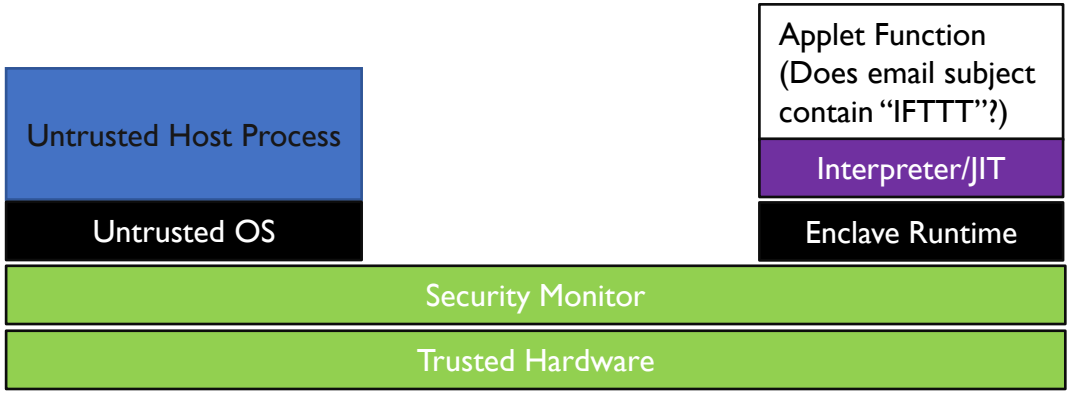


Challenge 2: Reducing Enclave TCB

Problem: Running an interpreter/JIT in the enclave increases the size of the software TCB in the enclave



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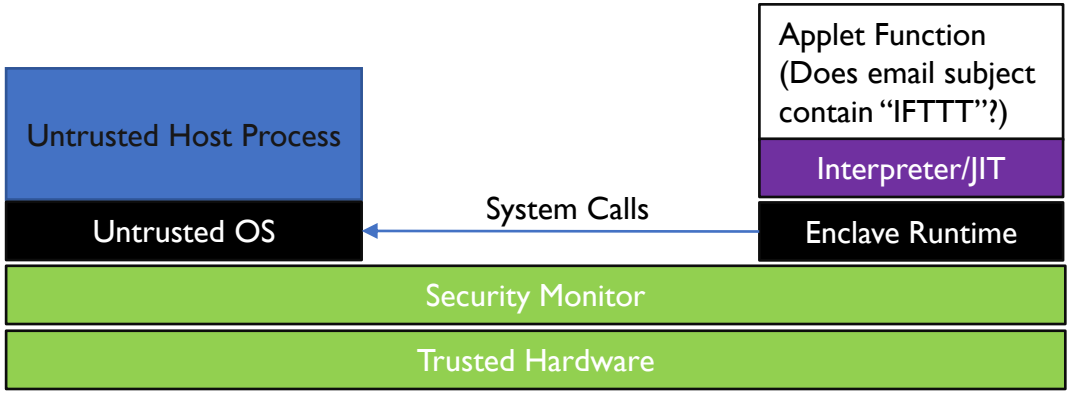
109 KLoC (Node.js frontend) + 935 KLoC (V8 Backend) + Large Syscall Interface to Untrusted OS



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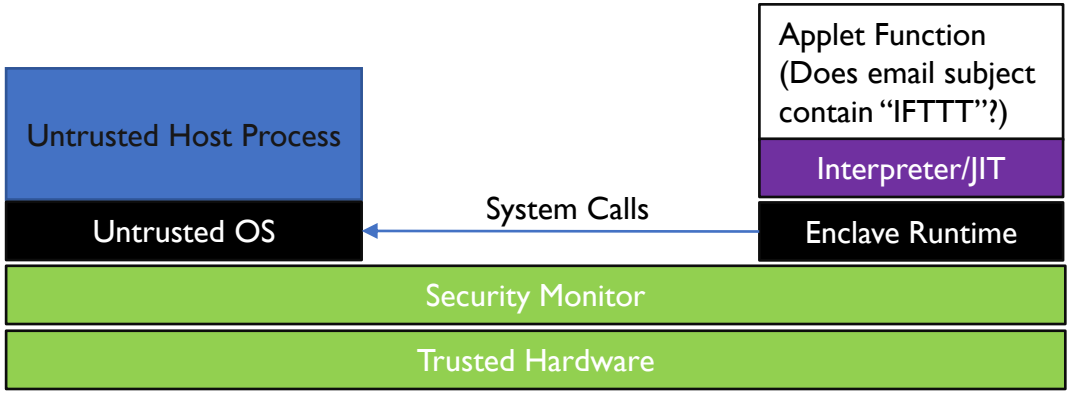

How to run TypeScript applets while reducing the software TCB of the enclave?

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Insight: Applets are pure computations that do not require all the features of an interpreter or OS support

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if (searchResult != -1) {
    Dropbox.appendToTextFileDb.append(Office365Mail.newEmailFrom.Body,
"processed.txt");
} else {
    Dropbox.appendToTextFileDb.skip();
}
```

```
@0 = private unnamed_addr constant [6 x i8] c"IFTTT\00", align 1
@1 = private unnamed_addr constant [14 x i8] c"processed.txt\00", align 1

define i64 @__rule_function() {
entry:
  %0 = call double @Office365Mail_newEmailFrom_Subject_search(i8* getelementptr inbounds ([6
x i8], [6 x i8]* @0, i32 0, i32 0))
  %searchResult = alloca double, align 8
  store double %0, double* %searchResult, align 8
  %1 = load double, double* %searchResult, align 8
  %2 = fcmp one double %1, -1.000000e+00
  br i1 %2, label %if.true, label %if.false

if.true:                                          ; preds = %entry
  %3 = call i8* @Office365Mail_newEmailFrom_Body()
  call void @Dropbox_appendToTextFileDb_append(i8* %3, i8* getelementptr inbounds ([14 x i8],
[14 x i8]* @1, i32 0, i32 0))
  br label %if.end

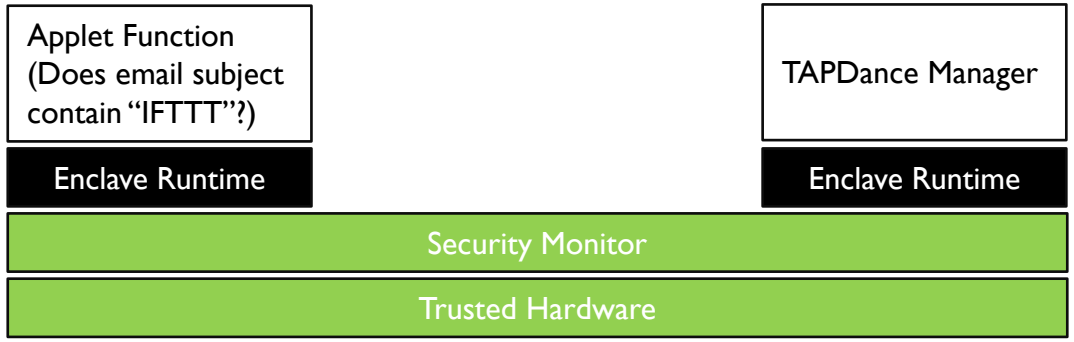
if.end:                                           ; preds = %if.true, %if.false
  ret i64 0

if.false:                                         ; preds = %entry
  call void @Dropbox_appendToTextFileDb_skip()
  br label %if.end
}
```

Challenge 3: Runtime Attestation

Idea 1: Have a long running attestation manager enclave that the user attests and provides keys to

Idea 2: Encrypt Applet Binary 🔑 such that it decrypts and runs only after successful attestation



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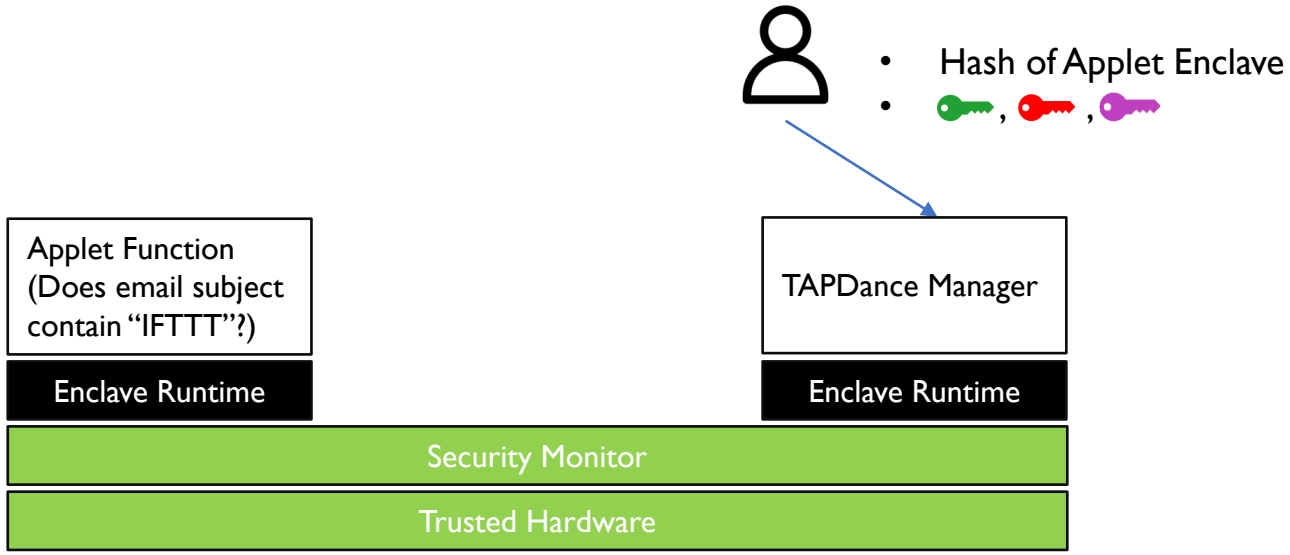

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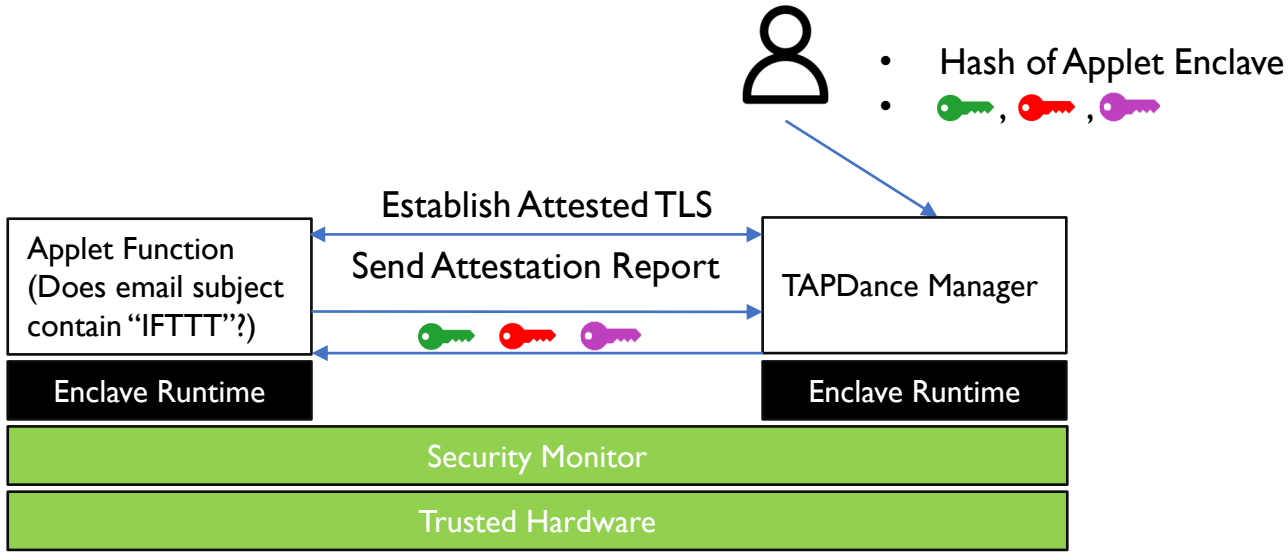

Summary of Problems and Solutions

1. Exfiltrate Trigger Event Data

2. Delay/Replay Trigger/Action Data

3. Misuse of OAuth Tokens

4. Size of Enclave TCB to run TypeScript Applets

5. Malicious User

Summary of Problems and Solutions

1. Exfiltrate Trigger Event Data → Use of Enclaves + Encryption of Trigger and Action Data

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Summary of Problems and Solutions

1. Exfiltrate Trigger Event Data → Use of Enclaves + Encryption of Trigger and Action Data

2. Delay/Replay Trigger/Action Data → Protocol with nonce and time service provided by SM

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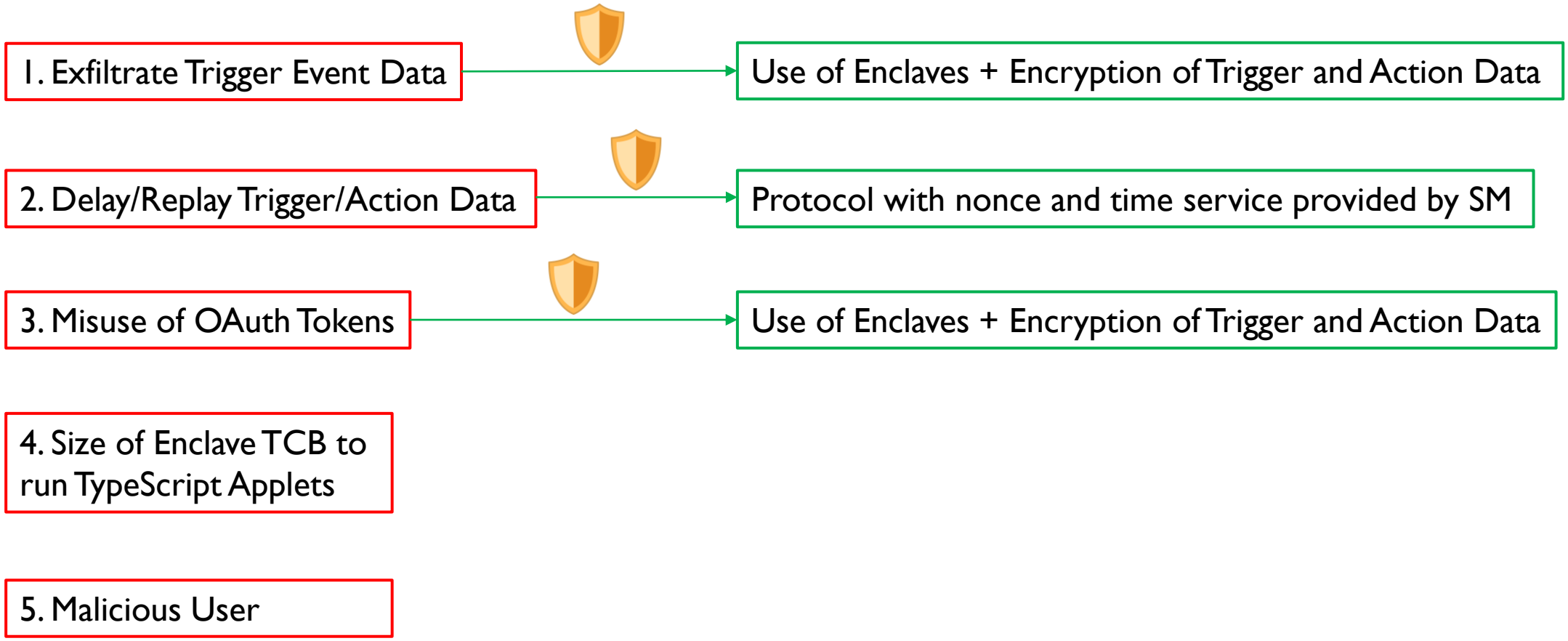

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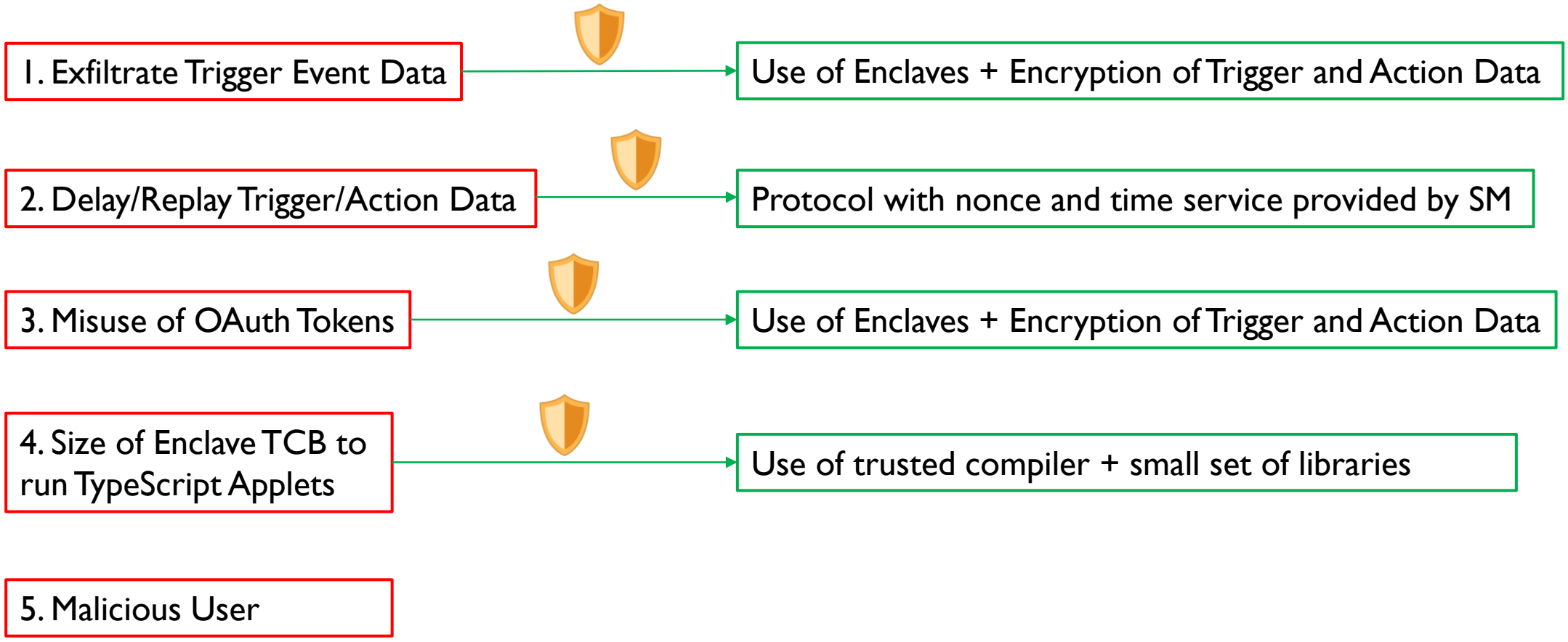

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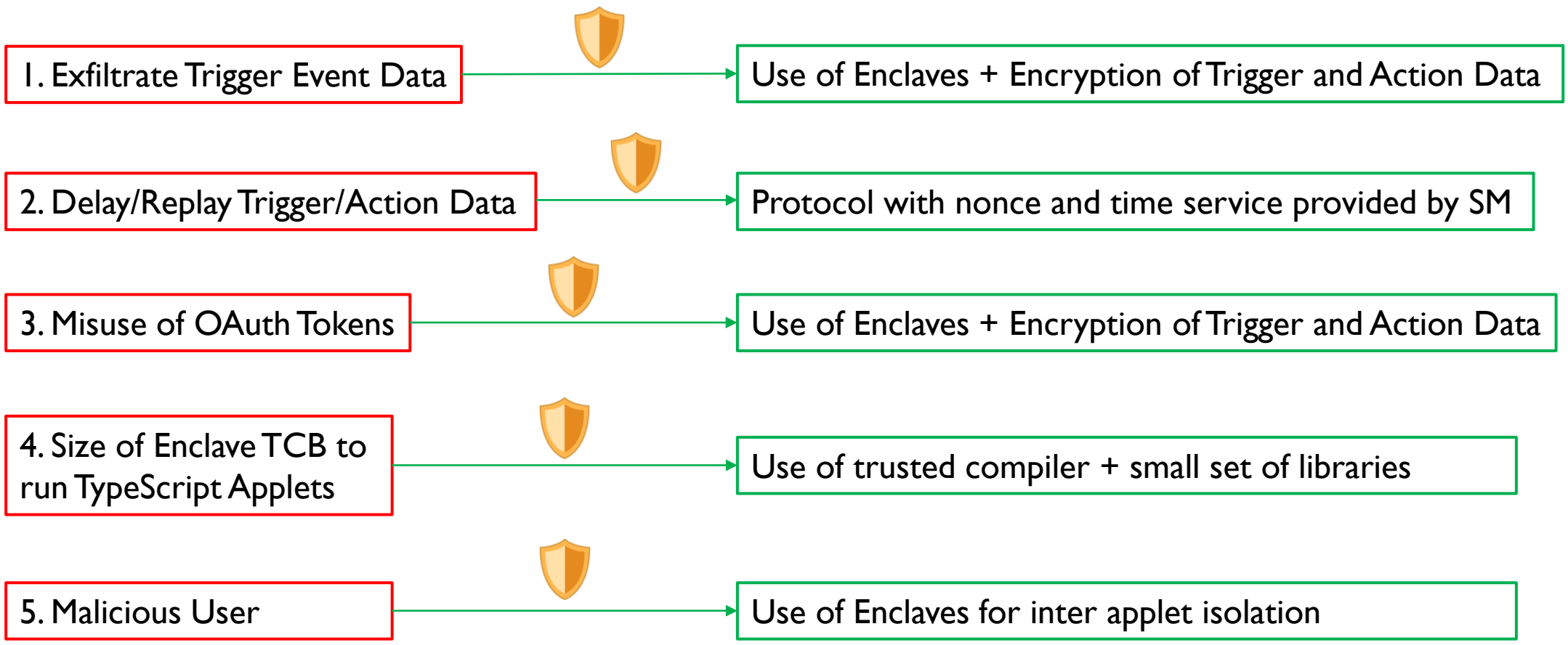

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Trigger and Action Services run on 32 core Intel Xeon E5-2630 processor running at 2.4 GHz with 128 GB RAM

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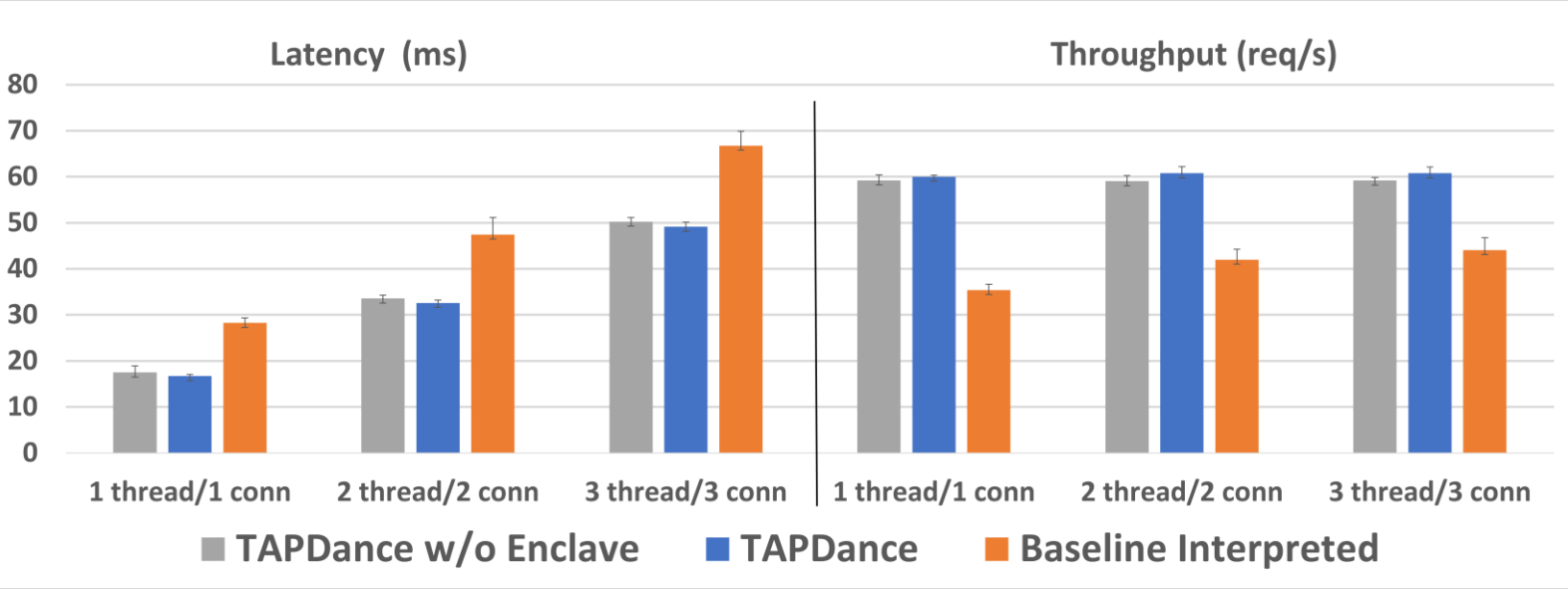

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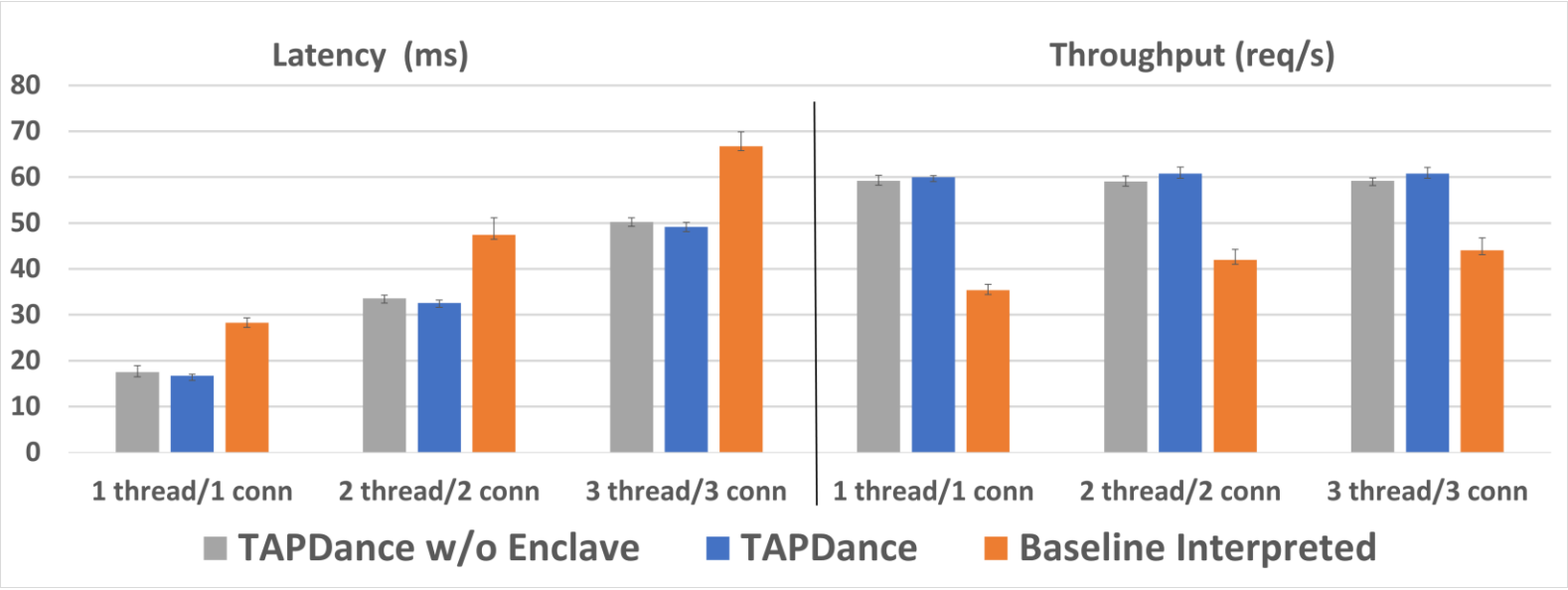

TAPDance has 32% lower latency than baseline

TAPDance has 33% higher throughput than baseline

Conclusion

- Current TAP architectures are fundamentally insecure – trigger and action data exposed to untrustworthy TAP system code
- Our insight is that applets are pure functions
- TAPDance uses the unique hardware protection of RISC-V to provide data privacy and applet execution integrity
- The performance loss is negligible

https://github.com/multifacet/tap_artifact/

Questions?