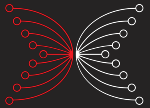
Smart Contracts

Smart Contracts & Bitcoin-Script

Lars Brünjes



INPUT | OUTPUT

January 9 2020

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- Transactions with several senders and/or receivers are possible.
- The state of the blockchain is determined by the set of all UTxOs.

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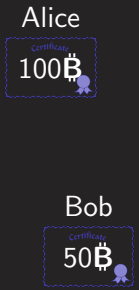
- No output value is negative.

Example: A Simple Transaction

Alice holds 100 ฿ and wants to send 40 ฿ to Bob, who has 50 ฿.



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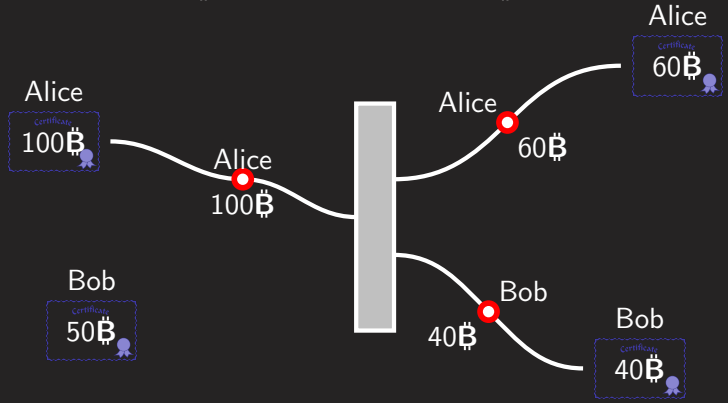

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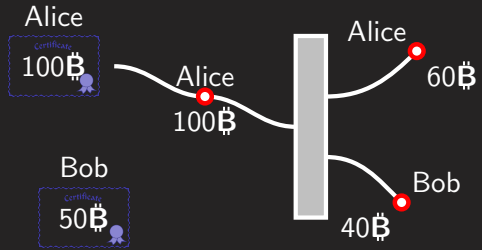
After sending 40 ₿ to Bob, Alice and Bob want to send 55 ₿ each to Charlie.



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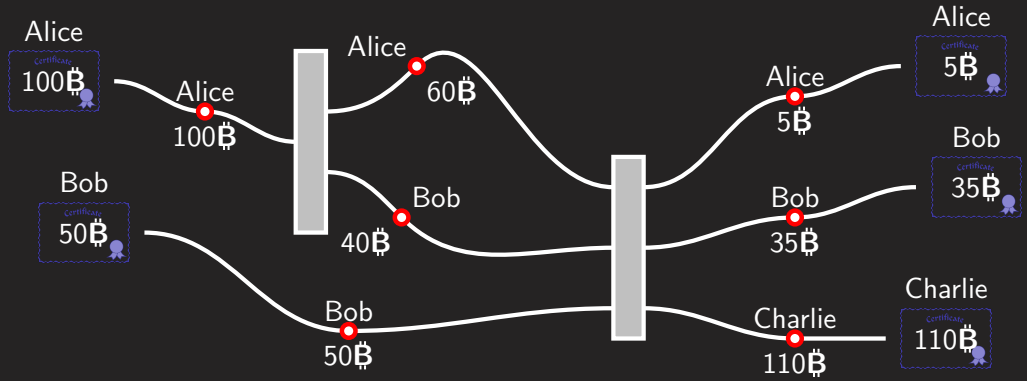

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- In this sense, smart contracts are *only* "words": Intent does not matter. All that matters is the actual code.

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- While verifying the inputs of a Bitcoin transaction, input- and output-scripts are combined and executed. The result from this execution decides whether the spending transaction is entitled to spend the output.
- Details depend on the specific cryptocurrency, but the principle stays the same: Programs decide under which circumstances money may be spent.

Flavours of Smart Contracts

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- Another option is to allow arbitrarily complex programs, but to make their execution "expensive": The initiator of a transaction has to pay a fee for each step the programs takes.
- The creators of Bitcoin have chosen the first option, Ethereum and Cardano use the second.

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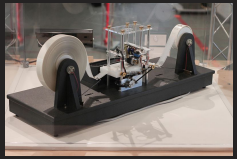

Figure: Turing-machine, reconstructed by Mike Davey. Image by Rocky Acosta, Creative Commons Licence.

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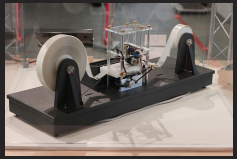

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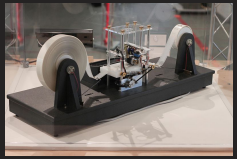

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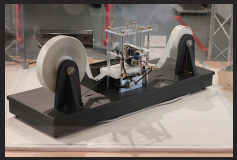

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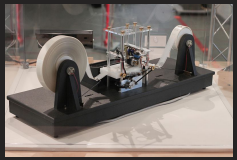
- Many more exotic systems (like λ-calculus) are Turing-complete as well.



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- To be more precise: Is there a program that will take an arbitrary program as input and then decide whether that program will halt?
- The answer is no! — Assume there was a Python-function `halt` solving the Halting-Problem. Then consider the following Python-function:

```
def paradox():
    if halt(paradox):
        while True:
            pass
```

If `halt` returns `True`, `paradox` gets stuck in an infinite loop, and if `halt` returns `False`, `paradox` will halt. Both are contradictions.

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- So if one chooses a Turing-complete smart-contract language, it is impossible to guarantee in advance whether a script will stop. Nor is it possible to know for how long the script will run, even if it eventually halts.
- As a consequence, one either has to decide against using a Turing-complete language or be prepared to interrupt a running script after some finite time has passed.

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- In spite of its simplicity, Bitcoin Script is quite powerful and flexible and allows for a plethora of different kinds of transaction verification.
- On the other hand, Bitcoin Script is too limited to allow for real smart contracts implementing complex financial transactions.

Stacks

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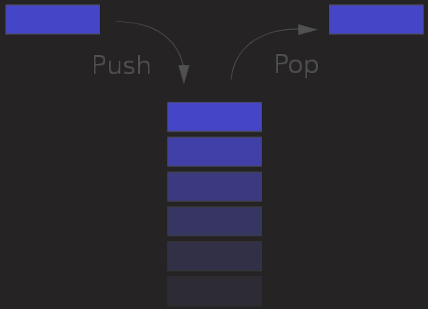
- Forth is a (relatively) popular higher programming language that is stack based as well. Other examples are the Java Virtual Machine (JVM) and Microsoft's Common Language Runtime (CLR).
- There are no variables in Bitcoin Script. Instead, data is put onto the stack and processed there.



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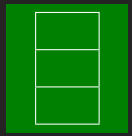
- The transaction is valid if all inputs are valid in this sense (and if all other conditions are satisfied, so the sum of all input-values is greater than the sum of all output-values etc.).
- This script-mechanism extends the simple UTxO-model by allowing for more complex input-validation, going beyond digital signature verification.

Example: Arithmetic

- The following program written in Bitcoin Script calculates $(2 + 3) \cdot 4$:
- `2 3 op_add 4 op_mul`

```
2
3
op_add
4
op_mul
```



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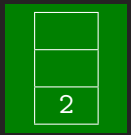
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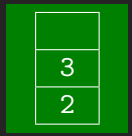

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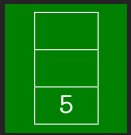

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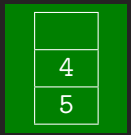

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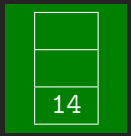

Exercises

- Compute $(10 - 3) \cdot (4 + 7)$ using Bitcoin Script! (*Hint*: Use `op_sub`!)
- Write a Bitcoin Script program which squares the number on top of the stack. (*Hint*: Use `op_dup`!)
- Write a Bitcoin Script programm which computes $x^2 + y^2$, where x and y are the two top-most numbers on the stack. (*Hint*: Use `op_swap`!)
- Write a Bitcoin Script Programm which computes $x \cdot y$ if $y < x$ and $x + y$ if $y >= x$, where x and y are the two top-most numbers on the stack (x on top, y below). (*Hint*: Use `op_2dup`, `op_lessthan`, `op_if`, `op_else`, and `op_endif`!)
- You can find a list of all Bitcoin-Script commands on `https://en.bitcoin.it/wiki/Script`.
- There is a nice online simulator on `https://siminchen.github.io/bitcoinIDE/build/editor.html`.

Pay to Public Key Hash in Bitcoin Script

- The vast majority of all Bitcoin transaction uses ordinary “hash of public key”-addresses.
- What do input- and output-scripts look like in this case?
  - `<sig> <pubKey>`
  - `op_dup op_hash160 <pubKeyHash> op_equalverify op_checksig`
  - The input-script puts the digital signature and the public key onto the stack. The output-script checks whether the hash of this public key has the right value and whether the signature is correct.

Pay to Public Key Hash — Example

- Input-Script:

```
304402200cc8b0471a38edad2ff9f9799521b7d948054817793c980eaf3a6637ddfb939702201c1a801461d4c3cf4de4e7336454dba0dd70b89d71f221e991cb6a79df1a860d01
02ce9f5972fe1473c9b6948949f676bbf7893a03c5b4420826711ef518ceefd8dc
```

- Output-Script:

```
op_dup op_hash160 1290b657a78e201967c22d8022b348bd5e23ce17 op_equalverify op_checksig
```

304402200cc8b0471a38ed...
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op_equalverify
op_checksig

Pay to Public Key Hash — Example

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```

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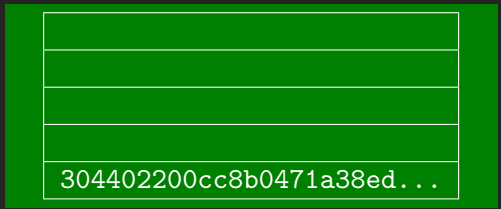

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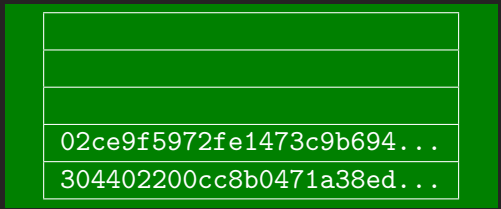

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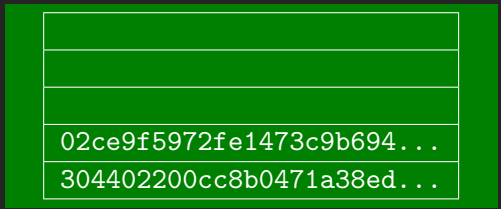

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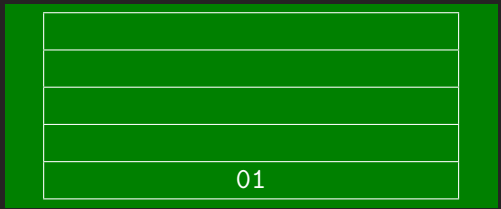

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- All commands following `op_return` are ignored.
- One possible application of this is to for example generate an output with value zero, then use a script which starts with `op_return` and contains arbitrary data afterwards.

Other kinds of Bitcoin Scripts — Riddles

- The output of transaction `a4bfa8ab6435ae5f25dae9d89e4eb67dfa94283ca751f393c1ddc5a837bbc31b` contained the following script:

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- This riddle was eventually solved: The given hash turned out to be the hash of the genesis-block-header.

Other kinds of Bitcoin Script — Incentivize Finding Hash Collisions

- In the year 2013, Peter Todd created scripts whose outputs could be spend by anybody who found a hash collision for SHA-1:

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op_2dup op_equal op_not op_verify op_sha1 op_swap op_sha1 op_equal
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- In February 2017, somebody claimed the reward of 2.48 ฿.

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```
<Datum-1>
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op_2dup
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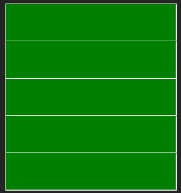

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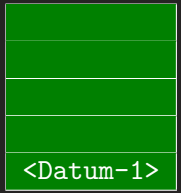

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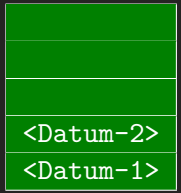

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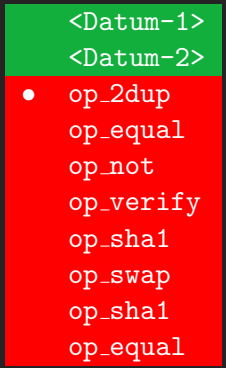

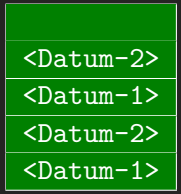

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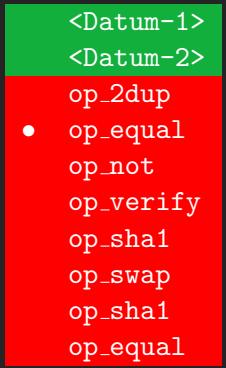

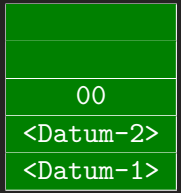

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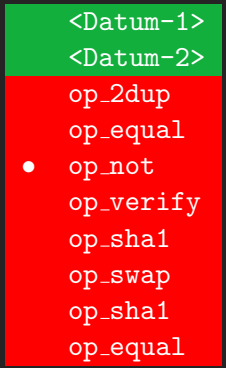

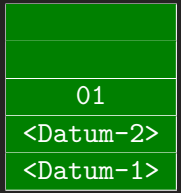

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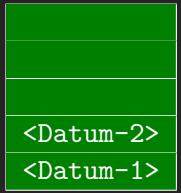

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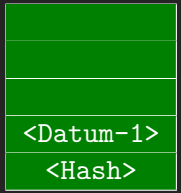

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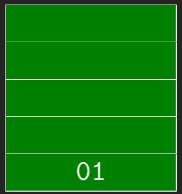

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- Both types of time locks are for example used in Bitcoin Lightning.

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- Instead they can use the following script:

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op_if <in drei Monaten> op_checklocktimeverify op_drop
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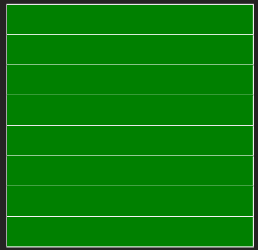
- After three months, Charlie and either Alice or Bob can use the following script instead:

```
0 <Sig-Alice/Bob> <Sig-Charlie> 1
```

Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



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- <Sig-Alice>
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- 00
- op_if
- <in drei Monaten>
- op_checklocktimeverify
- op_drop
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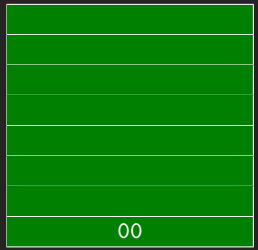
- op_checksigverify
- 01
- op_else
- 02
- op_endif
- <PubKey-Alice>
- <PubKey-Bob>
- 02
- op_checkmultisig



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op_endif
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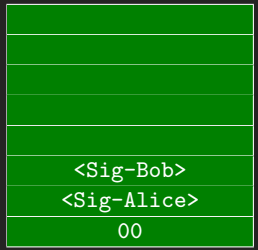
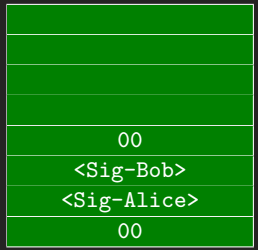
   op_checkmultisig
```



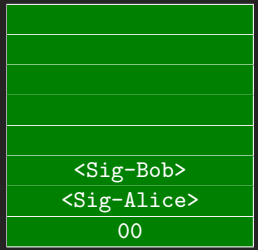
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



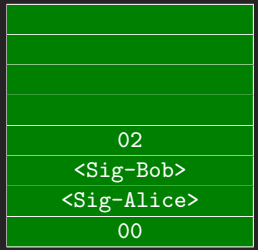
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



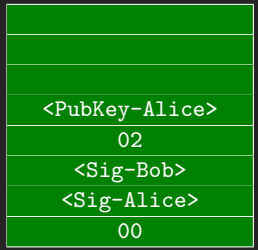
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



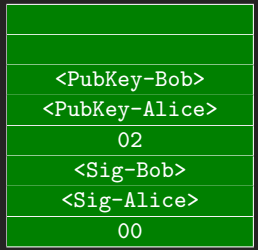
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



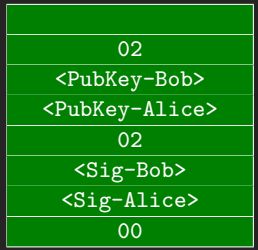
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



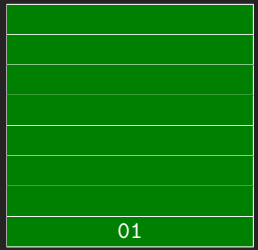
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



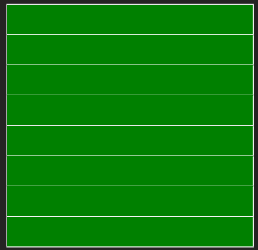
Time Lock Example — First Case

```
00
<Sig-Alice>
<Sig-Bob>
00
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



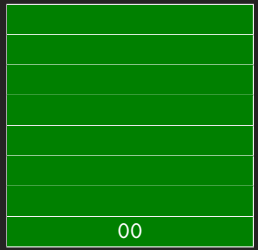
Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



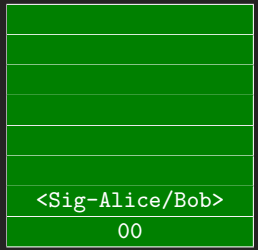
Time Lock Example — Second Case

- 00
  <Sig-Alice/Bob>
  <Sig-Charlie>
  01
  op_if
  <in drei Monaten>
  op_checklocktimeverify
  op_drop
  <PubKey-Charlie>
  op_checksigverify
  01
  op_else
  02
  op_endif
  <PubKey-Alice>
  <PubKey-Bob>
  02
  op_checkmultisig



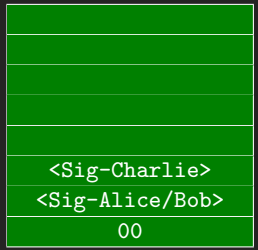
Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



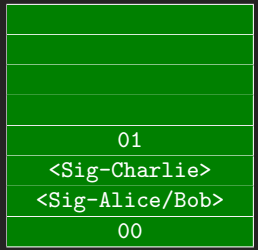
Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
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op_else
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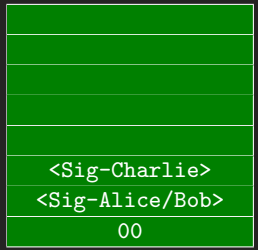
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



Time Lock Example — Second Case

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00
<Sig-Alice/Bob>
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op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
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<PubKey-Alice>
<PubKey-Bob>
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op_checkmultisig
```

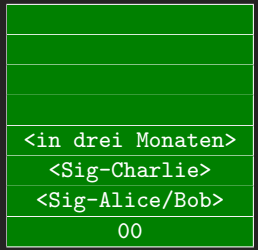

Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
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op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```

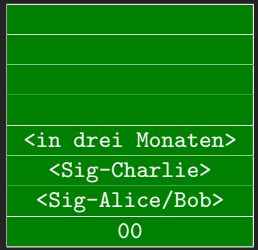

Time Lock Example — Second Case

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00
<Sig-Alice/Bob>
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01
op_if
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op_checklocktimeverify
op_drop
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<PubKey-Bob>
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op_checkmultisig
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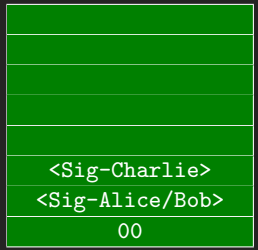

Time Lock Example — Second Case

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<Sig-Alice/Bob>
<Sig-Charlie>
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op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
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op_else
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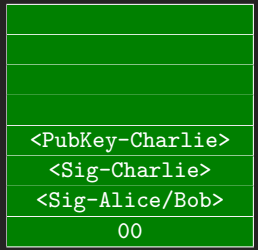
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
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op_else
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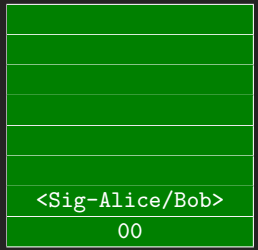
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



Time Lock Example — Second Case

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00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```

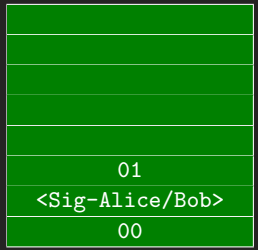

Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
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<PubKey-Alice>
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op_checkmultisig
```
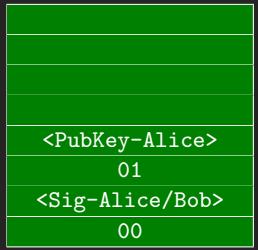
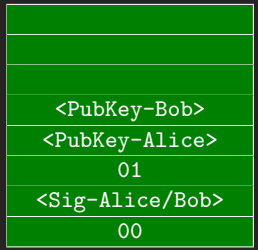
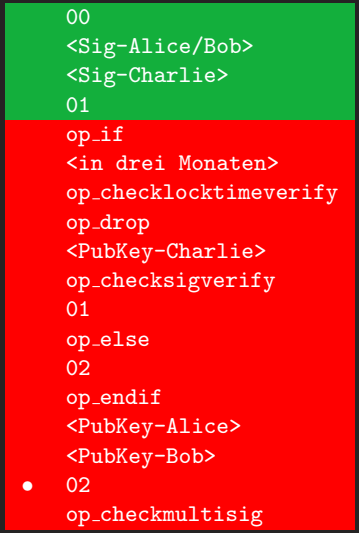



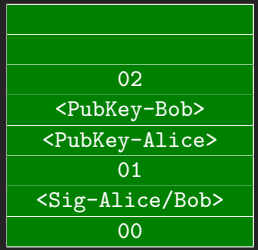
Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```



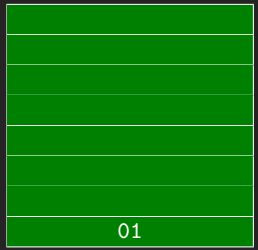
Time Lock Example — Second Case

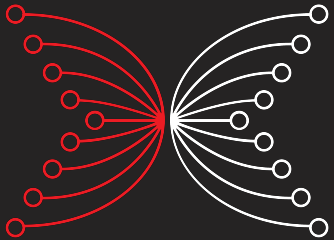




Time Lock Example — Second Case

```
00
<Sig-Alice/Bob>
<Sig-Charlie>
01
op_if
<in drei Monaten>
op_checklocktimeverify
op_drop
<PubKey-Charlie>
op_checksigverify
01
op_else
02
op_endif
<PubKey-Alice>
<PubKey-Bob>
02
op_checkmultisig
```





INPUT | OUTPUT