Script:
Bitcoin's Programming Language

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Code Samples and Slides at:
github.com/ryanxcharles/blockchain-university

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Outline

Script Interpreter
P2SH
Standard Transactions
Opcodes
Validating Transactions and Blocks
Advanced Scripts

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Script Interpreter

Input scriptSig 0	Output scriptPubkey 0
Input scriptSig 1	Output scriptPubkey 1
Input scriptSig 2	Output scriptPubkey 2

Transactions have inputs and outputs.
Inputs have scripts. Outputs have scripts.

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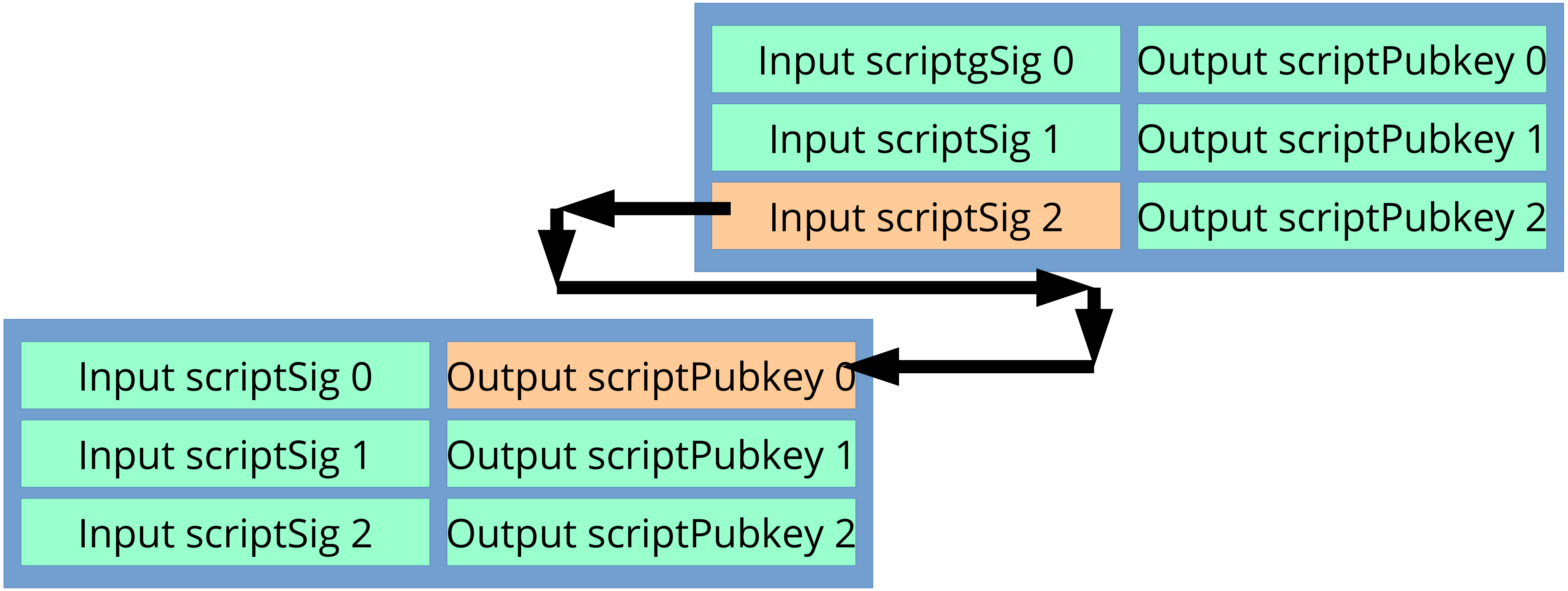
Script Interpreter



Each input links to the output of an earlier transaction.

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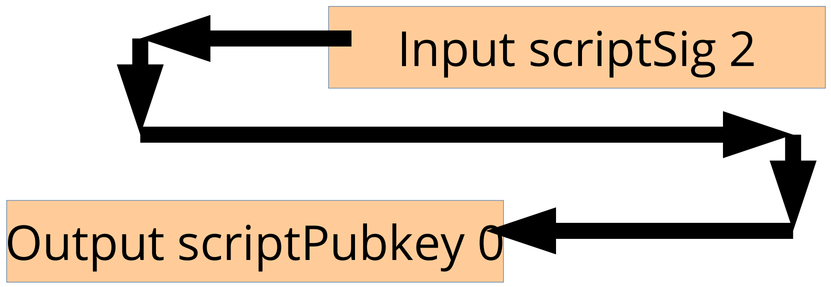

To validate an input, the scriptSig is executed and the scriptPubkey from the earlier transaction is executed.

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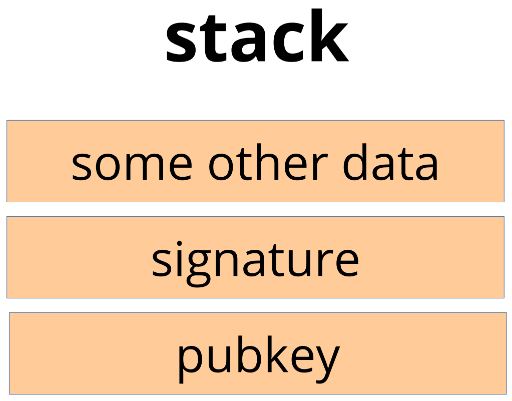
Script Interpreter

- The **stack** is the memory of bitcoin. Bitcoin does not have a heap. There is also an **alt stack** and things can be moved from stack to alt stack or from alt stack to stack.
- You can push and pop to the stack.
- Pubkeys and sigs are pushed to the stack. Other things like numbers can be pushed to the stack, if that's what the script does.



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Script Interpreter

- To validate an input, the scriptSig is executed and the scriptPubkey from the earlier transaction is executed.
- After the scriptSig is executed, the stack is left the same, and the scriptPubkey runs starting with the same stack.
- Note that they are executed in “reverse” order – scriptSig first, from the later transaction, then scriptPubkey, from the earlier transaction

Input scriptSig 2	Output scriptPubkey 0

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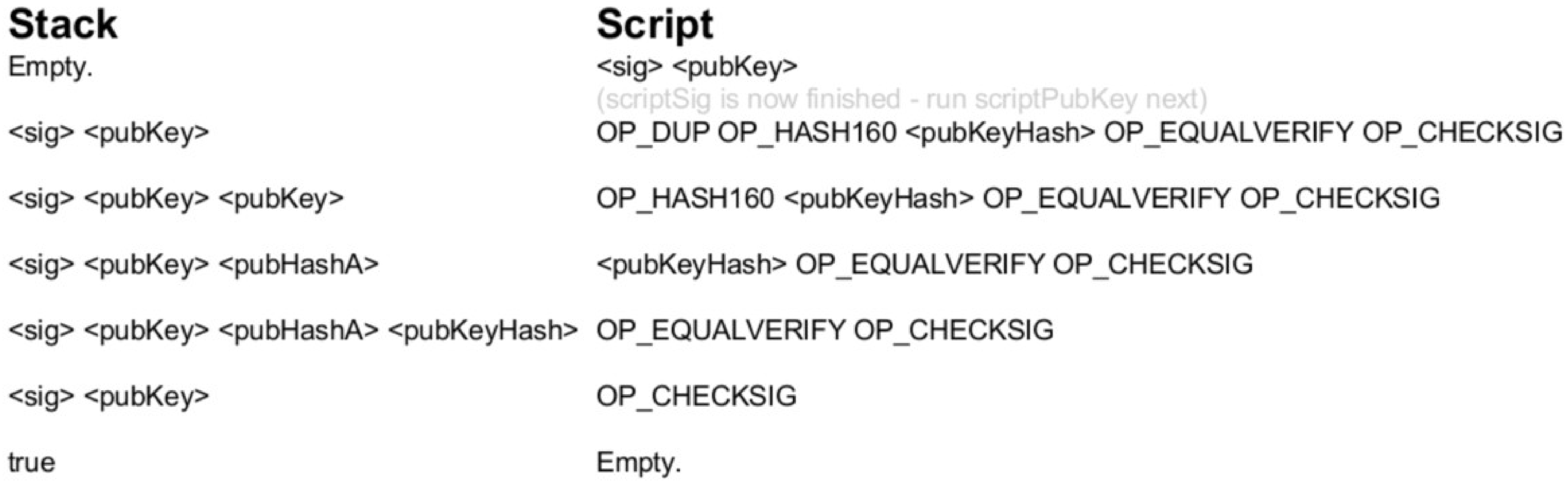
Script Interpreter

pubkeyhash example, a.k.a. normal bitcoin address and transaction



Stack	Script
Empty.	<sig> <pubKey> (scriptSig is now finished - run scriptPubKey next)
<sig> <pubKey>	OP_DUP OP_HASH160 <pubKeyHash> OP_EQUALVERIFY OP_CHECKSIG
<sig> <pubKey> <pubKey>	OP_HASH160 <pubKeyHash> OP_EQUALVERIFY OP_CHECKSIG
<sig> <pubKey> <pubHashA>	<pubKeyHash> OP_EQUALVERIFY OP_CHECKSIG
<sig> <pubKey> <pubHashA> <pubKeyHash>	OP_EQUALVERIFY OP_CHECKSIG
<sig> <pubKey>	OP_CHECKSIG
true	Empty.

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Opcodes

- One byte specifying an operation.

- OP_FALSE: 0x00,
- OP_0: 0x00,
- OP_PUSHDATA1: 0x4c,
- OP_PUSHDATA2: 0x4d,
- OP_PUSHDATA4: 0x4e,
- OP_1NEGATE: 0x4f,
- OP_RESERVED: 0x50,
- OP_TRUE: 0x51,
- OP_1: 0x51,
- OP_2: 0x52,
- OP_3: 0x53,
- OP_4: 0x54,
- OP_5: 0x55,
- OP_6: 0x56,
- OP_7: 0x57,
- OP_8: 0x58,
- OP_9: 0x59,
- OP_10: 0x5a,
- OP_11: 0x5b,
- OP_12: 0x5c,
- OP_13: 0x5d,
- OP_14: 0x5e,
- OP_15: 0x5f,
- OP_16: 0x60,
- OP_NOP: 0x61,
- OP_VER: 0x62,
- OP_IF: 0x63,
- OP_NOTIF: 0x64,
- OP_VERIF: 0x65,
- OP_VERNOTIF: 0x66,
- OP_ELSE: 0x67,
- OP_ENDIF: 0x68,
- OP_VERIFY: 0x69,
- OP_RETURN: 0x6a,
- ... ~175 total, including push data

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Push Ops

- 0 – 0x80: That many bytes are pushed to the stack.
  - e.g., 0x05 0x0404040404 pushes “0404040404” to the stack
- PUSHDATA1: The following byte specifies amount of data to push
  - e.g.: OP_PUSHDATA1 0x03 0x010203 pushes “010203” to the stack
- PUSHDATA2: The following two bytes (Uint16BE) specify the amount of data to push
- PUSHDATA4: The following four bytes (Uint32BE) specify the amount of data to push
- Anything 80 bytes or less can be pushed with a single byte push OP rather than PUSHDATAX – that includes signatures, usually ~70 bytes, and pubkeys, ~33 or ~65 bytes. p2sh redeemScripts, often containing multiple pubkeys, require PUSHDATA1 or PUSHDATA2

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Number Ops

- 0 = 0x00 = OP_0 = OP_FALSE
- OP_1 = 81 = 0x51 = OP_TRUE
- OP_2 = 82 = 0x52
- …
- OP_16 = 96 = 0x60
- Pushes that number to the stack. The number is a ScriptNum – zero bytes if 0, one byte if 1 - 16

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Control Ops

- OP_IF: 0x63 – checks that top item on stack is true
- OP_NOTIF: 0x64
- OP_ELSE: 0x67
- OP_ENDIF: 0x68
- OP_RETURN: 0x6a ← **commonly used**

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Stack Ops

- Rearrange things on the stack or alt stack
- OP_TOALTSTACK: 0x6b
- OP_FROMALTSTACK: 0x6c
- OP_2DROP: 0x6d
- OP_2DUP: 0x6e
- OP_3DUP: 0x6f
- OP_2OVER: 0x70
- OP_2ROT: 0x71
- OP_2SWAP: 0x72
- OP_IFDUP: 0x73
- OP_DEPTH: 0x74
- OP_DROP: 0x75
- OP_DUP: 0x76 ← **commonly used**
- OP_NIP: 0x77
- OP_OVER: 0x78
- OP_PICK: 0x79
- OP_ROLL: 0x7a
- OP_ROT: 0x7b
- OP_SWAP: 0x7c
- OP_TUCK: 0x7d

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Splice Ops

- Rearrange bytes of the top stack item
- OP_CAT: 0x7e
- OP_SUBSTR: 0x7f
- OP_LEFT: 0x80
- OP_RIGHT: 0x81
- OP_SIZE: 0x82

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Bitwise Ops

- Rearrange bytes of the top stack item
- OP_INVERT: 0x83
- OP_AND: 0x84
- OP_OR: 0x85
- OP_XOR: 0x86
- OP_EQUAL: 0x87
- OP_EQUALVERIFY: 0x88, ← **commonly used**
- OP_RESERVED1: 0x89
- OP_RESERVED2: 0x8a

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Numeric Ops

- Not commonly used – some are disabled

- OP_1ADD: 0x8b
- OP_1SUB: 0x8c
- OP_2MUL: 0x8d
- OP_2DIV: 0x8e
- OP_NEGATE: 0x8f
- OP_ABS: 0x90
- OP_NOT: 0x91
- OP_0NOTEQUAL: 0x92

- OP_ADD: 0x93
- OP_SUB: 0x94
- OP_MUL: 0x95
- OP_DIV: 0x96
- OP_MOD: 0x97
- OP_LSHIFT: 0x98
- OP_RSHIFT: 0x99

- OP_BOOLAND: 0x9a
- OP_BOOLOR: 0x9b
- OP_NUMEQUAL: 0x9c
- OP_NUMEQUALVERIFY: 0x9d
- OP_NUMNOTEQUAL: 0x9e
- OP_LESSTHAN: 0x9f
- OP_GREATERTHAN: 0xa0
- OP_LESSTHANOREQUAL: 0xa1
- OP_GREATERTHANOREQUAL: 0xa2
- OP_MIN: 0xa3
- OP_MAX: 0xa4

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Cryptography Ops

- OP_RIPEMD160: 0xa6
- OP_SHA1: 0xa7
- OP_SHA256: 0xa8
- OP_HASH160: 0xa9 ← **commonly used**
- OP_HASH256: 0xaa
- OP_CODESEPARATOR: 0xab
- OP_CHECKSIG: 0xac ← **commonly used**
- OP_CHECKSIGVERIFY: 0xad
- OP_CHECKMULTISIG: 0xae ← **commonly used**
- OP_CHECKMULTISIGVERIFY: 0xaf

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Standard Script Types

- pubkeyhash ← most common
- pubkey
- multisig
- p2sh
- OP_RETURN

- Since p2sh redeemScript is itself a script, combinations like “p2sh multisig” are possible – p2sh multisig is most common use of p2sh

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pubkeyhash

- scriptSig:
- <sig> <pubkey>

- scriptPubkey:
- OP_DUP OP_HASH160 <address> OP_EQUALVERIFY OP_CHECKSIG

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pubkey (rare)

- scriptSig:
- <sig>

- scriptPubkey:
- <pubkey> OP_CHECKSIG

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multisig

- scriptSig:
- OP_0 <sig1> <sig2> ... <sigm> ← starts with extra OP_0 because of famous multisig bug – pops one too many items from stack

- scriptPubkey:
- OP_m <pubkey1> <pubkey2> ... <pubkeyn> OP_n OP_CHECKMULTISIG

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p2sh multisig

- scriptSig:
- OP_0 <sig1> <sig2> ... <sigm> <redeemScript>

- scriptPubkey:
- OP_HASH160 <redeemScriptHash> OP_EQUALVERIFY

- redeemScript:
- OP_m <pubkey1> <pubkey2> ... <pubkeyn> OP_n OP_CHECKMULTISIG

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OP_RETURN

- scriptPubkey:
- OP_RETURN <up to 40 (80?) bytes of data>

- How to put arbitrary data in an output if necessary.

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Standard Transaction Rules

- If a transaction has all standard inputs/outputs, it is standard
- Standard transactions are relayed by default
- Non-standard transactions can still be valid, and can be in a block, if a miner receives it somehow and chooses to include it
- Complicated scripts are thus discouraged; preventing hypothetical DOS attacks on the network and blockchain bloat

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Validating a Transaction

- Be sure that there is at least one input
- Be sure that transaction is not over MAX_BLOCK_SIZE
- Be sure that values are not negative or greater than MAX_MONEY
- Be sure inputs are not duplicated
- Be sure that inputs are not null
- Run script interpreter on all inputs and be sure no inputs are invalid

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