

Standardization for the black hat

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① bada55.cr.yp.to “BADA55
Crypto” including “How to
manipulate curve standards: a
white paper for the black hat.”

② projectbullrun.org
including “Dual EC: a
standardized back door.”

Includes joint work with
(in alphabetical order):

Tung Chou (1)

Chitchanok Chuengsatiansup (1)

Andreas Hülsing (1)

Eran Lambooi (1)

Tanja Lange (1) (2)

Ruben Niederhagen (1) (2)

Christine van Vredendaal (1)

Inspirational previous work:

ANSI, ANSSI, Brainpool, IETF,
ISO, NIST, OSCCA, SECG, and
especially our buddies at NSA.

The DES key size

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IBM: 64! NSA: 48!

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NBS (now NIST) continues to
promote DES for two decades,
drastically increasing cost
of the inevitable upgrade.

Random nonces in DSA/ECDSA

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Standardize anyway.

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Add complicated *options* for deterministic nonces, while preserving old options.

Denial of service via flooding

Suspected terrorists Alice and Bob are aided and abetted by “auditors” (= “cryptanalysts” = “reviewers”) checking for exploitable security problems in cryptographic systems.

Example: SHA-3 competition involved 200 cryptographers around the world and took years of sustained public effort. How can we slip a security problem past all of them?

During the same period, NIST also published FIPS 186-3 (signatures), FIPS 198-1 (authentication), SP 800-38E (disk encryption), SP 800-38F (key wrapping), SP 800-56C (key derivation), SP 800-57 (key management), SP 800-67 (block encryption), SP 800-108 (key derivation), SP 800-131A (key lengths), SP 800-133 (key generation), SP 800-152 (key management), and related protocol documents such as SP 800-81r1.

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Scientific advances? No!

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And NIST is just the tip of the crypto standardization iceberg.

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2004: Number-theoretic RNGs provide “increased assurance.”

2006: Dual EC

“is the only DRBG mechanism in this Recommendation whose security is related to a hard problem in number theory.”

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Obviously not! Standardize!

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2007 Shumow–Ferguson: Dual EC has a back door. Would have been easy to build Q with the key.

2007 Schneier: Never use Dual EC. “Both NIST and the NSA have some explaining to do.”

Did Shumow and Ferguson
show us the key? No!

Maintain and promote Dual EC
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Even after being caught, continue to burn auditors' time by demanding that they jump higher.

NSA's Dickie George, 2014: Gee, Dual EC is really hard to exploit!

System vs. ecosystem

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Auditor looks at one system,
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Auditor's starting assumption: random numbers for Alice and Bob are created by an RNG.

Reality: random numbers are created by a much more complicated ecosystem that designs, evaluates, standardizes, selects, implements, and deploys RNGs. (Same for other crypto.)

This is a critical change in perspective. Auditor is stuck defending the wrong targets!

The ecosystem has many weaknesses that are not visible inside any particular system.

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Then manipulate selection.

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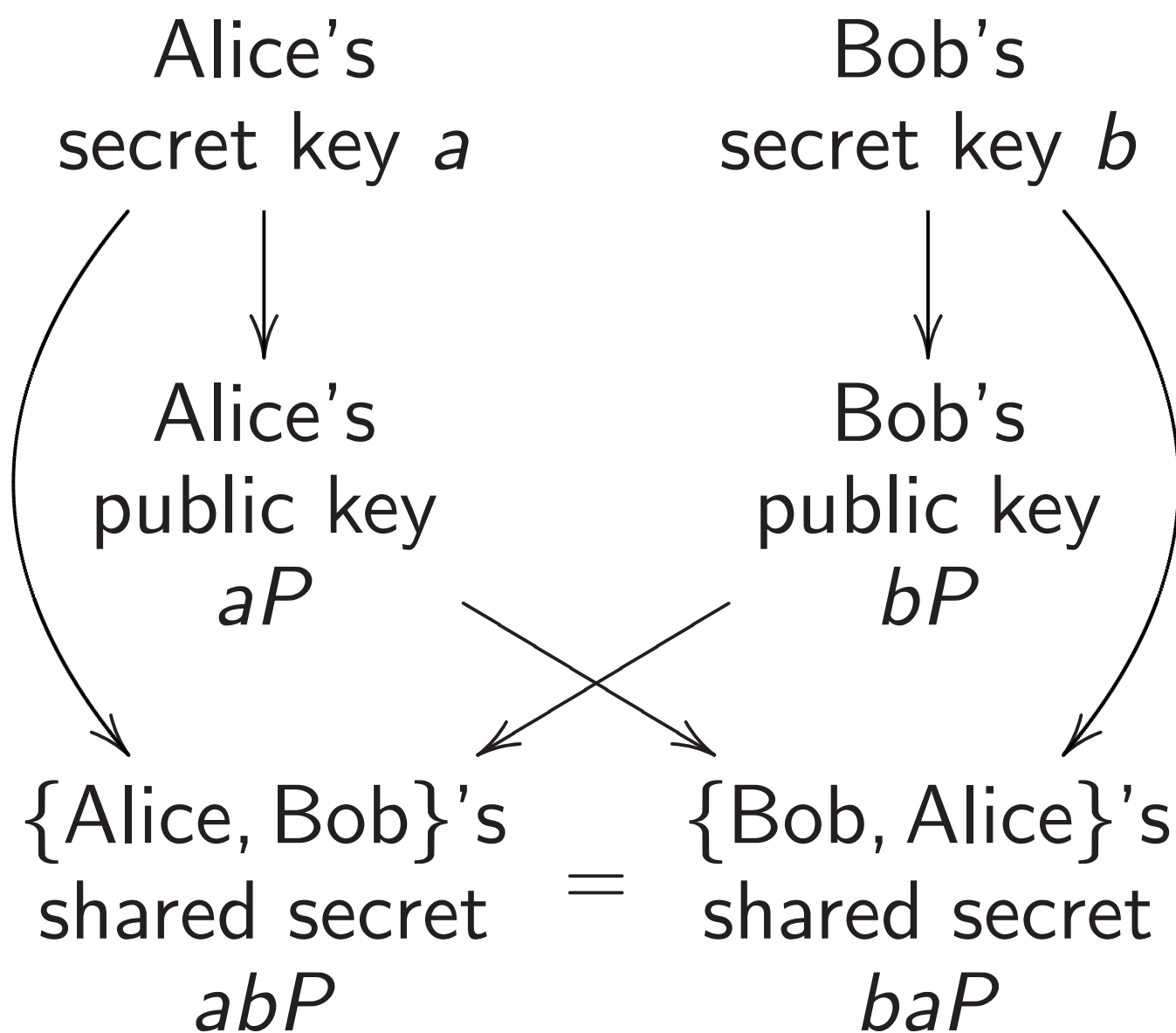
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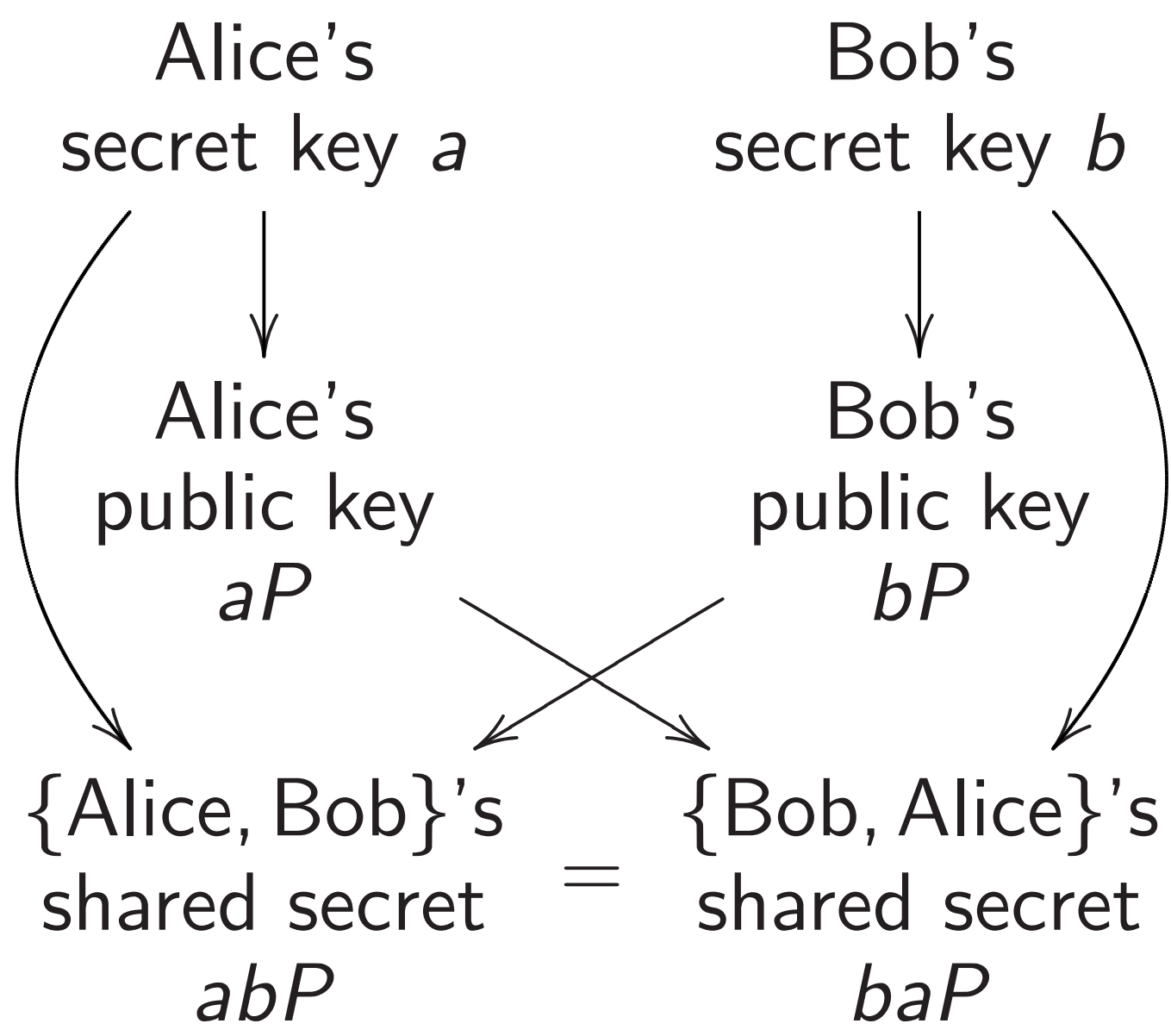
Deter publication of weaknesses:

“This attack is trivial. Reject.”

Textbook key exchange
using standard point P
on a standard elliptic curve E :

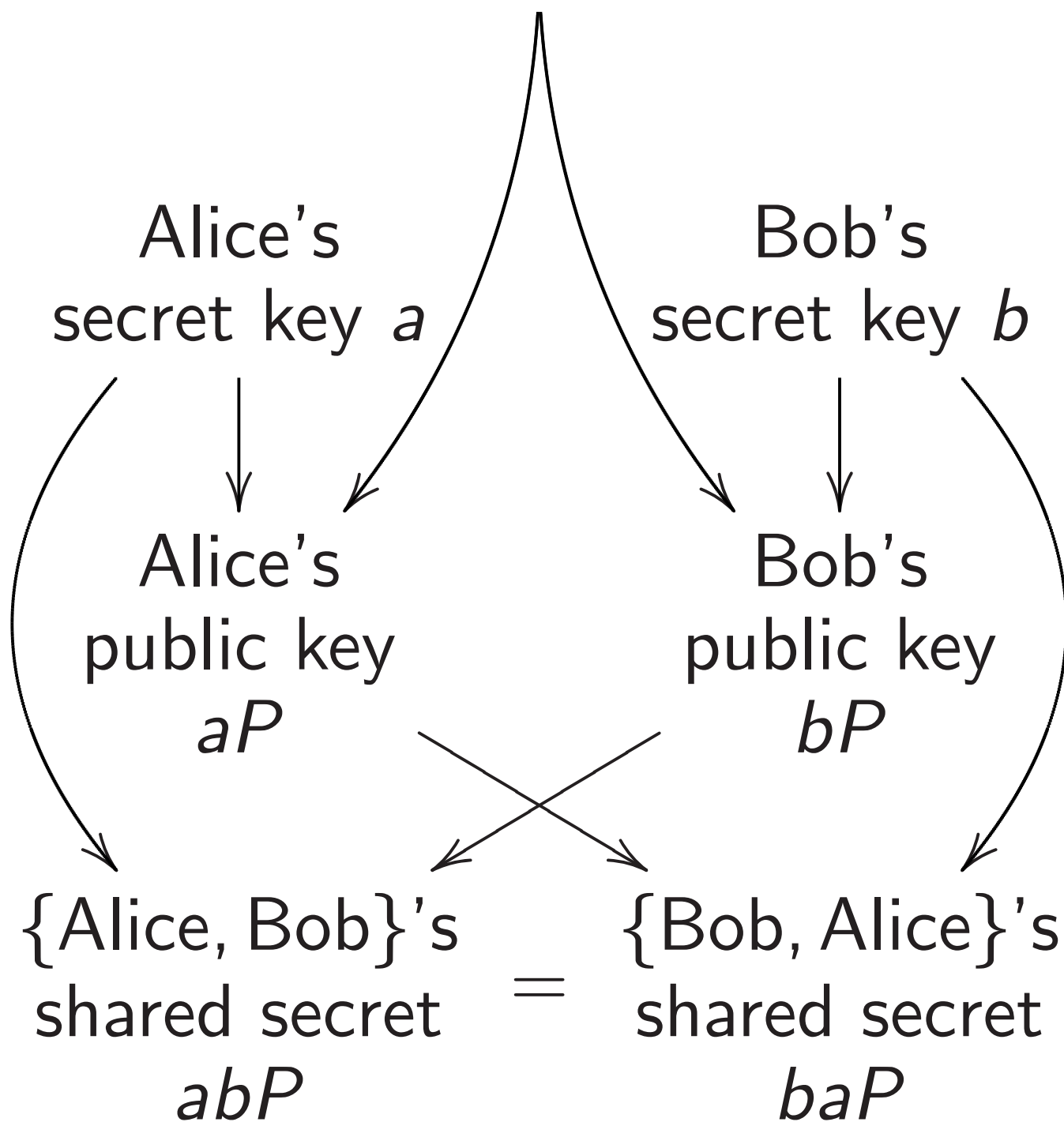


Textbook key exchange
 using standard point P
 on a standard elliptic curve E :



Security depends on choice of E .

Our partner Jerry's
choice of E, P



This is not the same picture!

One final example

2005 Brainpool standard:

“The choice of the seeds from which the [NIST] curve parameters have been derived is not motivated leaving an essential part of the security analysis open.

... **Verifiably pseudo-random.**

The [Brainpool] curves shall be generated in a pseudo-random manner using seeds that are generated in a systematic and comprehensive way.”


```

import hashlib
def hash(seed): h = hashlib.sha1(); h.update(seed); return h.digest()
seedbytes = 20

p = 0xD7C134AA264366862A18302575D1D787B09F075797DA89F57EC8C0FF
k = GF(p); R.<x> = k[]

def secure(A,B):
    if k(B).is_square(): return False
    n = EllipticCurve([k(A),k(B)]).cardinality()
    return (n < p and n.is_prime()
            and Integers(n)(p).multiplicative_order() * 100 >= n-1)

def int2str(seed,bytes):
    return ''.join([chr((seed//256^i)%256) for i in reversed(range(bytes))])

def str2int(seed):
    return Integer(seed.encode('hex'),16)

def update(seed):
    return int2str(str2int(seed) + 1,len(seed))

def fullhash(seed):
    return str2int(hash(seed) + hash(update(seed))) % 2^223

def real2str(seed,bytes):
    return int2str(Integer(floor(RealField(8*bytes+8)(seed)*256^bytes)),bytes)

nums = real2str(exp(1)/16,7*seedbytes)
S = nums[2*seedbytes:3*seedbytes]
while True:
    A = fullhash(S)
    if not (k(A)*x^4+3).roots(): S = update(S); continue
    S = update(S)
    B = fullhash(S)
    if not secure(A,B): S = update(S); continue
    print 'p',hex(p).upper()
    print 'A',hex(A).upper()
    print 'B',hex(B).upper()
    break

```

2015: We carefully implemented the curve-generation procedure from the Brainpool standard.

Previous slide: 224-bit procedure.

Output of this procedure:

```
p D7C134AA264366862A18302575D1D787B09F075797DA89F57EC8C0FF
A 2B98B906DC245F2916C03A2F953EA9AE565C3253E8AEC4BFE84C659E
B 68AEC4BFE84C659EBB8B81DC39355A2EBFA3870D98976FA2F17D2D8D
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```

The standard 224-bit Brainpool curve **is not the same curve:**

```
p D7C134AA264366862A18302575D1D787B09F075797DA89F57EC8C0FF
A 68A5E62CA9CE6C1C299803A6C1530B514E182AD8B0042A59CAD29F43
B 2580F63CCFE44138870713B1A92369E33E2135D266DBB372386C400B
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B 2580F63CCFE44138870713B1A92369E33E2135D266DBB372386C400B
```

Next slide: a procedure that **does** generate the standard Brainpool curve.

```

import hashlib
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seedbytes = 20

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k = GF(p); R.<x> = k[]

def secure(A,B):
    n = EllipticCurve([k(A),k(B)]).cardinality()
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def int2str(seed,bytes):
    return ''.join([chr((seed//256i)%256) for i in reversed(range(bytes))])

def str2int(seed):
    return Integer(seed.encode('hex'),16)

def update(seed):
    return int2str(str2int(seed) + 1,len(seed))

def fullhash(seed):
    return str2int(hash(seed) + hash(update(seed))) % 2223

def real2str(seed,bytes):
    return int2str(Integer(floor(RealField(8*bytes+8)(seed)*256bytes)),bytes)

nums = real2str(exp(1)/16,7*seedbytes)
S = nums[2*seedbytes:3*seedbytes]
while True:
    A = fullhash(S)
    if not (k(A)*x4+3).roots(): S = update(S); continue
    while True:
        S = update(S)
        B = fullhash(S)
        if not k(B).is_square(): break
    if not secure(A,B): S = update(S); continue
    print 'p',hex(p).upper()
    print 'A',hex(A).upper()
    print 'B',hex(B).upper()
    break

```

Did Brainpool check before publication? After publication? Did they know before 2015?

Brainpool procedure is advertised as “systematic”, “comprehensive”, “completely transparent”, etc. Surely we can say the same for *both* procedures.

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Interesting Brainpool quote: “It is envisioned to provide additional curves on a regular basis.”

We made a new 224-bit curve using standard NIST P-224 prime.

To avoid Brainpool's complications of concatenating hash outputs: We upgraded from SHA-1 to state-of-the-art maximum-security SHA3-512.

Also upgraded to requiring maximum twist security.

Brainpool uses $\exp(1) = e$ and $\arctan(1) = \pi/4$, and MD5 uses $\sin(1)$, so we used $\cos(1)$.

We also used much simpler pattern of searching for seeds.

```

import simplesha3
hash = simplesha3.sha3512

p = 2224 - 296 + 1
k = GF(p)
seedbytes = 20

def secure(A,B):
    n = EllipticCurve([k(A),k(B)]).cardinality()
    return (n.is_prime() and (2*p+2-n).is_prime()
            and Integers(n)(p).multiplicative_order() * 100 >= n-1
            and Integers(2*p+2-n)(p).multiplicative_order() * 100 >= 2*p+2-n-1)

def int2str(seed,bytes):
    return ''.join([chr((seed//256i)%256) for i in reversed(range(bytes))])

def str2int(seed):
    return Integer(seed.encode('hex'),16)

def complement(seed):
    return ''.join([chr(255-ord(s)) for s in seed])

def real2str(seed,bytes):
    return int2str(Integer(RealField(8*bytes)(seed)*256bytes),bytes)

sizeofint = 4
nums = real2str(cos(1),seedbytes - sizeofint)
for counter in xrange(0,256sizeofint):
    S = int2str(counter,sizeofint) + nums
    T = complement(S)
    A = str2int(hash(S))
    B = str2int(hash(T))
    if secure(A,B):
        print 'p',hex(p).upper()
        print 'A',hex(A).upper()
        print 'B',hex(B).upper()
        break

```

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We actually generated >1000000 curves for this prime, each having a Brainpool-like explanation, even without complicating hashing, seed search, etc.; e.g., BADA55-VPR2-224 uses $\exp(1)$.

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See bada55.cr.jp.to for much more: full paper; scripts; detailed Brainpool analysis; manipulating “minimal” primes and curves (Microsoft “NUMS”); manipulating security criteria.