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 Lambooij [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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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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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!
We successfully denied service.

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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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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 standard. Pay people to use it.

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

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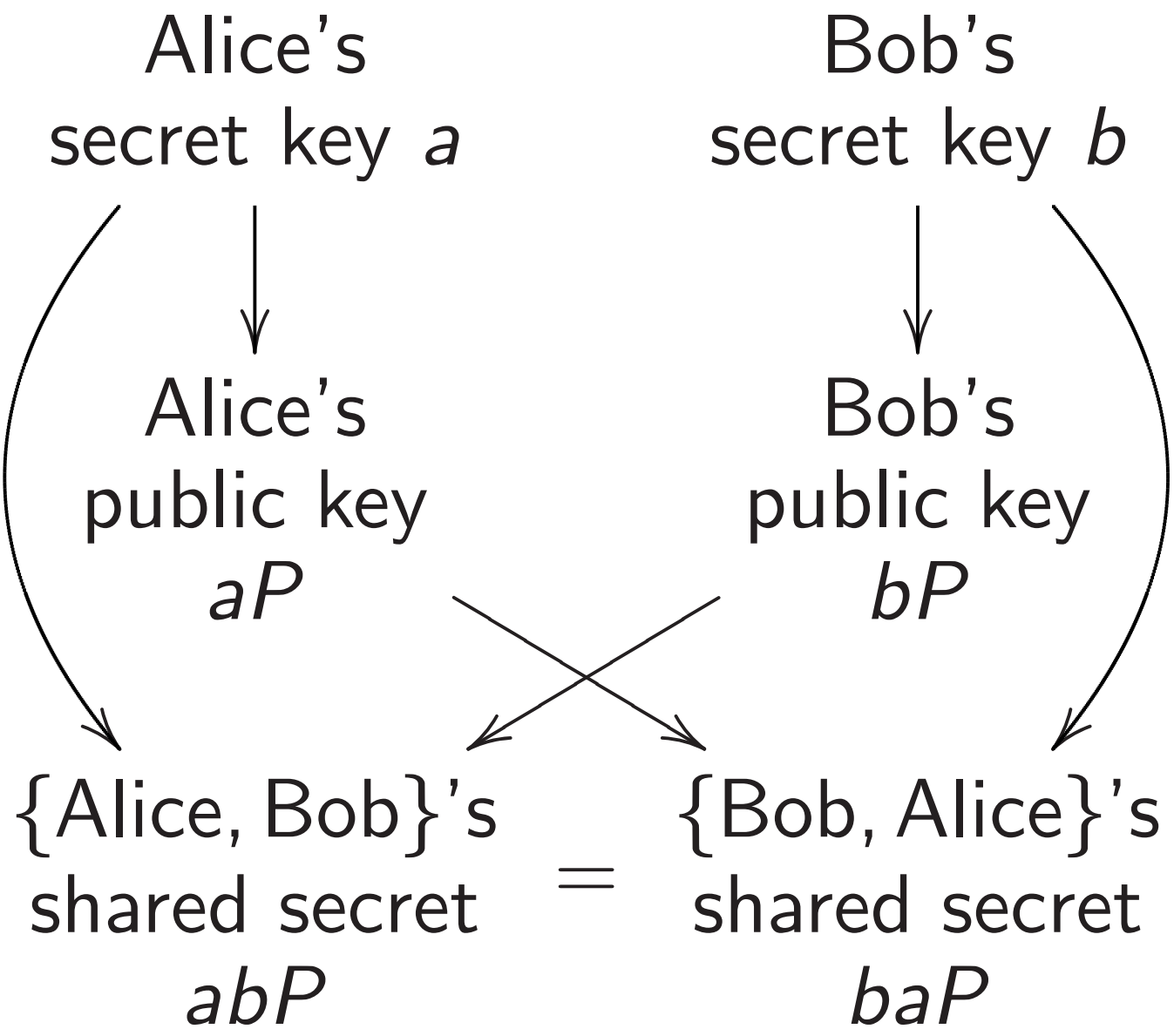
Deter publication of weaknesses: "This attack is trivial. Reject."

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



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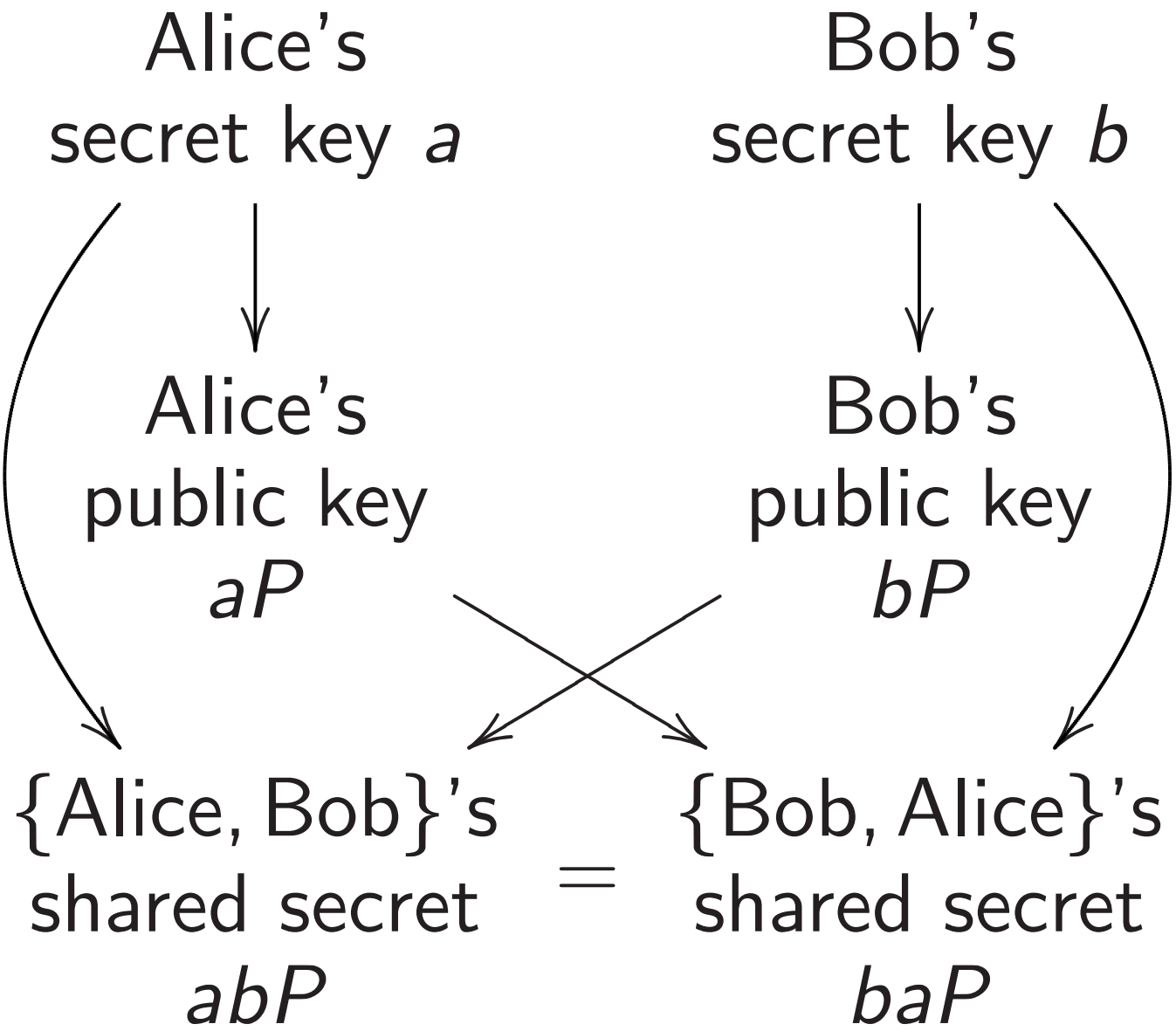
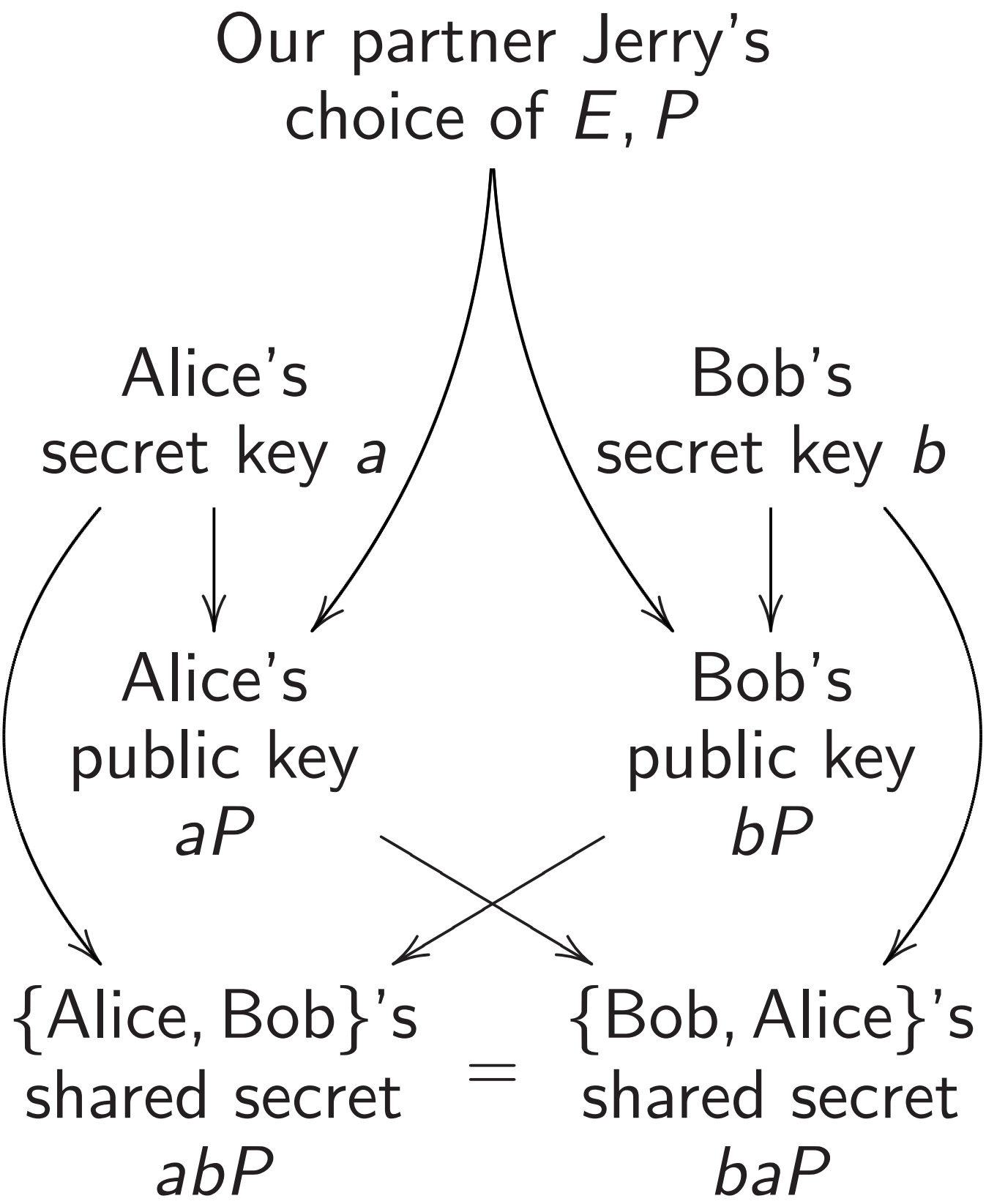


Security depends on choice of E.



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:

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p  D7C134AA264366862A18302575D1D787B09F075797DA89F57EC8C0FF
A  2B98B906DC245F2916C03A2F953EA9AE565C3253E8AEC4BFE84C659E
B  68AEC4BFE84C659EBB8B81DC39355A2EBFA3870D98976FA2F17D2D8D
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The standard 224-bit Brainpool curve **is not the same curve**:

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B  2580F63CCFE44138870713B1A92369E33E2135D266DBB372386C400B
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Next slide: a procedure that **does** generate the standard Brainpool curve.

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def real2str(seed,bytes):
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  while True:
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    B = fullhash(S)
    if not k(B).is_square(): break
  if not secure(A,B): S = update(S); continue
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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 = 2^224 - 2^96 + 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//256^i)%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)*256^bytes),bytes)

sizeofint = 4
nums = real2str(cos(1),seedbytes - sizeofint)
for counter in xrange(0,256^sizeofint):
  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.yp.to` for much more: full paper; scripts; detailed Brainpool analysis; manipulating "minimal" primes and curves (Microsoft "NUMS"); manipulating security criteria.