A New Standard of Ukraine: The Kupyna Hash Function (DSTU 7564:2014)

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Outline

- Retrospective
- The new Ukrainian hash function Kupyna
- Performance comparison with other ciphers
- Conclusions

Retrospective

- theoretical attacks on the previous hash standard GOST 34.311:2009 (GOST 34.311-95)
  - its computational inefficiency in modern platforms
- 256-bit length of a hash value is insufficient for some applications
- replacement in the other post-Soviet states
  - the Belarusian standard STB 34.101.31-2011 defines a hash function
  - GOST R 34.11-2012 ("Streebog") is the new hash function in Russia

Theoretical weaknesses of GOST 34.311:2009

- Complexities of cryptanalytic attacks less than brute-force:
  - pre-image attacks 2^{192}
  - a collision attack 2^{105}
- Cryptanalytic attacks are theoretical
  - memory complexity is 2^{75}

The requirements for the prospective hash function

- the lengths of hash values are 256, 384 and 512 bits
  - supporting lengths from 8 to 512 bits with the 8-bit step
- no limitations on processing messages
- support of the additional mode message authentication code (MAC)
- a conservative approach to the development
  - the use of well-proven constructions
- optimized for modern 64-bit platforms
  - effective in 32-bit implementations
- performance better than GOST 34.311:2009

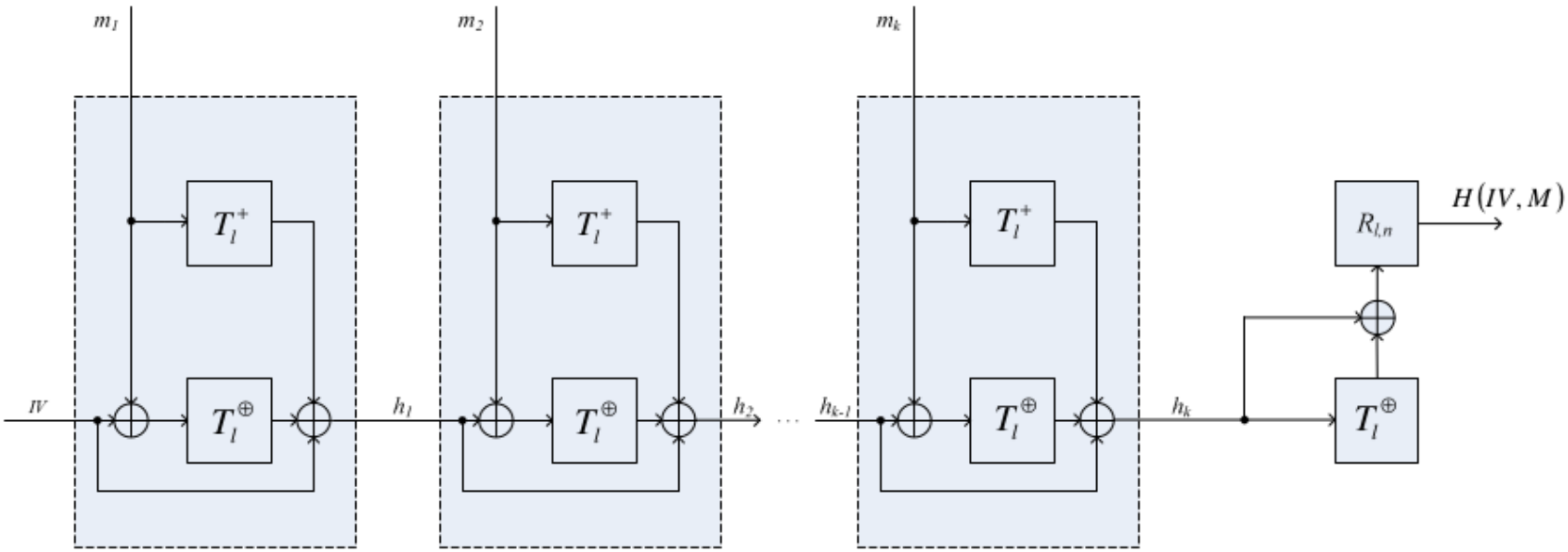
Kupyna: parameters

Table: General parameters for Kupyna

Hash code length (n)	Internal state size (l)	Number of rounds (t)	Rows of the state matrix (c)
$8 \leq n \leq 256$	512	10	8
$256 < n \leq 512$	1024	14	16

Kupyna: high-level structure

$$l = \begin{cases} 512, & \text{if } 8 \leq n \leq 256; \\ 1024, & \text{if } 256 < n \leq 512. \end{cases} \qquad IV = \begin{cases} 1 \ll 510, & \text{if } l = 512; \\ 1 \ll 1023, & \text{if } l = 1024. \end{cases}$$



Kupyna: $T_l^{\oplus}$ and T_l^{+}

$$T_l^{\oplus} = \prod_{\nu=0}^{t-1} \left(\psi \circ \tau^{(l)} \circ \pi' \circ \kappa_\nu^{(l)} \right) \quad T_l^{+} = \prod_{\nu=0}^{t-1} \left(\psi \circ \tau^{(l)} \circ \pi' \circ \eta_\nu^{(l)} \right)$$

- based on the block cipher Kalyna defined in DSTU 7624:2014
- both $T_l^{\oplus}$ and T_l^{+} are pseudorandom functions
- differ in
  - round constants
  - operations of mixing round constants ($mod 2^{64}$, XOR)

Kupyna: constants

$$T_l^{\oplus} : C^i = \begin{bmatrix} 00 \oplus i & 10 \oplus i & 20 \oplus i & 30 \oplus i & 40 \oplus i & 50 \oplus i & \ldots & \text{f}0 \oplus i \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \\ 00 & 00 & 00 & 00 & 00 & 00 & \ldots & 00 \end{bmatrix}$$

$$T_l^{+} : C^i = \begin{bmatrix} \text{f3} & \text{f3} & \text{f3} & \text{f3} & \text{f3} & \text{f3} & \ldots & \text{f3} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \text{f0} & \ldots & \text{f0} \\ \text{f0} \oplus i & \text{e0} \oplus i & \text{d0} \oplus i & \text{c0} \oplus i & \text{b0} \oplus i & a0 \oplus i & \ldots & 00 \oplus i \end{bmatrix}$$

Kupyna: properties of S-boxes

Property	S-box			
	1	2	3	4
Nonlinearity	104			
Min. algebraic degree of Boolean functions	7			
Max. value of difference distribution table	8			
Max. value of linear approximation table	24			
Algebraic immunity	3			
Number of cycles	4	4	6	4
Minimal cycle length	6	8	4	4

Equivalent to ones defined in DSTU 7624:2014

Kupyna: permutation of bytes

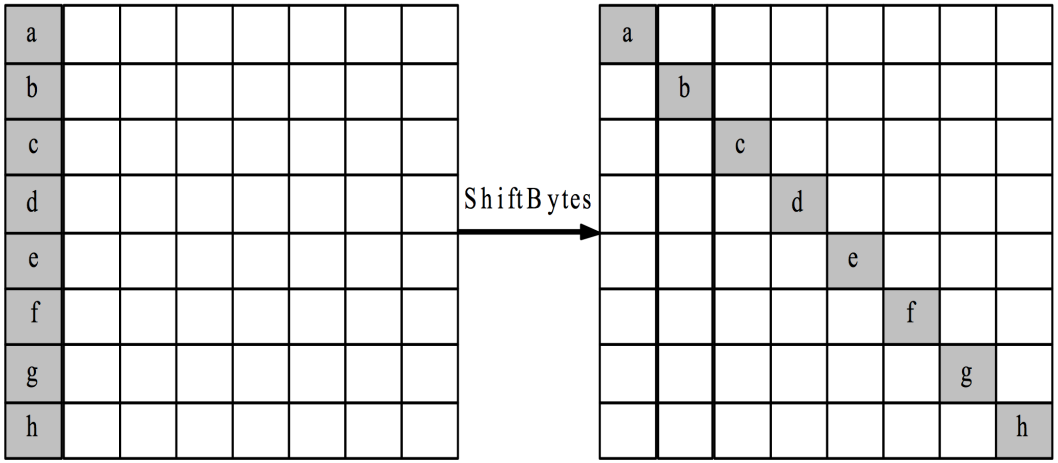


Figure: For $l = 512$

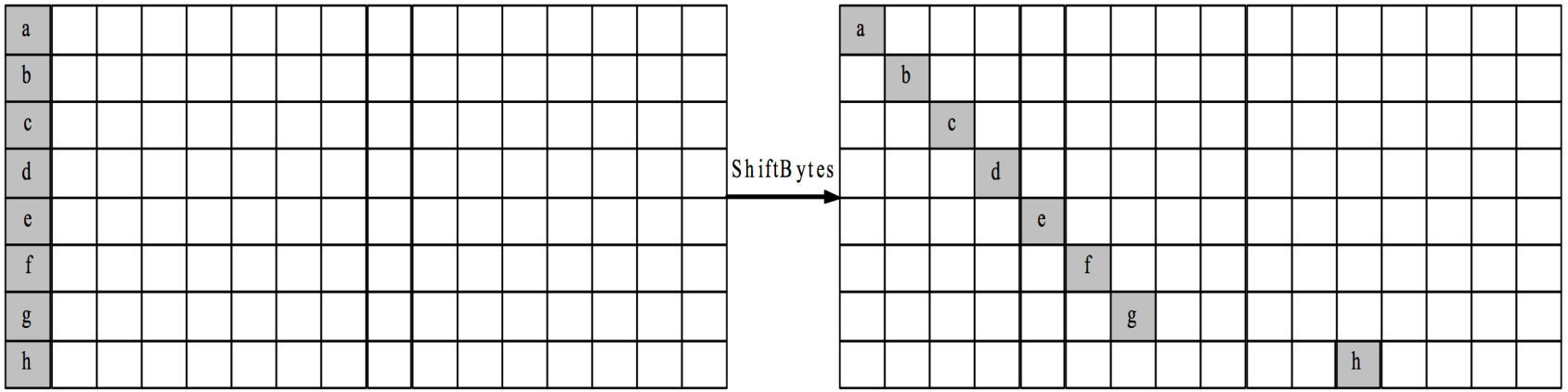


Figure: For $l = 1024$

Kupyna: linear transformation

$$\begin{bmatrix} b_0 \\ b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \\ b_6 \\ b_7 \end{bmatrix} = \begin{bmatrix} 01\cdot a_0 \oplus 01\cdot a_1 \oplus 05\cdot a_2 \oplus 01\cdot a_3 \oplus 08\cdot a_4 \oplus 06\cdot a_5 \oplus 07\cdot a_6 \oplus 04\cdot a_7 \\ 04\cdot a_0 \oplus 01\cdot a_1 \oplus 01\cdot a_2 \oplus 05\cdot a_3 \oplus 01\cdot a_4 \oplus 08\cdot a_5 \oplus 06\cdot a_6 \oplus 07\cdot a_7 \\ 07\cdot a_0 \oplus 04\cdot a_1 \oplus 01\cdot a_2 \oplus 01\cdot a_3 \oplus 05\cdot a_4 \oplus 01\cdot a_5 \oplus 08\cdot a_6 \oplus 06\cdot a_7 \\ 06\cdot a_0 \oplus 07\cdot a_1 \oplus 04\cdot a_2 \oplus 01\cdot a_3 \oplus 01\cdot a_4 \oplus 05\cdot a_5 \oplus 01\cdot a_6 \oplus 08\cdot a_7 \\ 08\cdot a_0 \oplus 06\cdot a_1 \oplus 07\cdot a_2 \oplus 04\cdot a_3 \oplus 01\cdot a_4 \oplus 01\cdot a_5 \oplus 05\cdot a_6 \oplus 01\cdot a_7 \\ 01\cdot a_0 \oplus 08\cdot a_1 \oplus 06\cdot a_2 \oplus 07\cdot a_3 \oplus 04\cdot a_4 \oplus 01\cdot a_5 \oplus 01\cdot a_6 \oplus 05\cdot a_7 \\ 05\cdot a_0 \oplus 01\cdot a_1 \oplus 08\cdot a_2 \oplus 06\cdot a_3 \oplus 07\cdot a_4 \oplus 04\cdot a_5 \oplus 01\cdot a_6 \oplus 01\cdot a_7 \\ 01\cdot a_0 \oplus 05\cdot a_1 \oplus 01\cdot a_2 \oplus 08\cdot a_3 \oplus 06\cdot a_4 \oplus 07\cdot a_5 \oplus 04\cdot a_6 \oplus 01\cdot a_7 \end{bmatrix}$$

- the brunch number is 9 (the MDS matrix)
- effective software and software-hardware implementations

Transformations from Kalyna

Advantages of using transformations from the block cipher Kalyna

- high and ultra high security level
- high performance of cryptographic transformations
- compact implementation
- the Rijndael-like structure provides pseudorandom properties of permutations even for constant round keys (or their absence at all)

Design principles of the hash function Kupyna

security - performance - compactness

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- protection from known cryptanalytic methods
- focus on modern platforms (64-bit)
  - the effectiveness on existing (32-bit)

Cryptanalytic attack against Kupyna

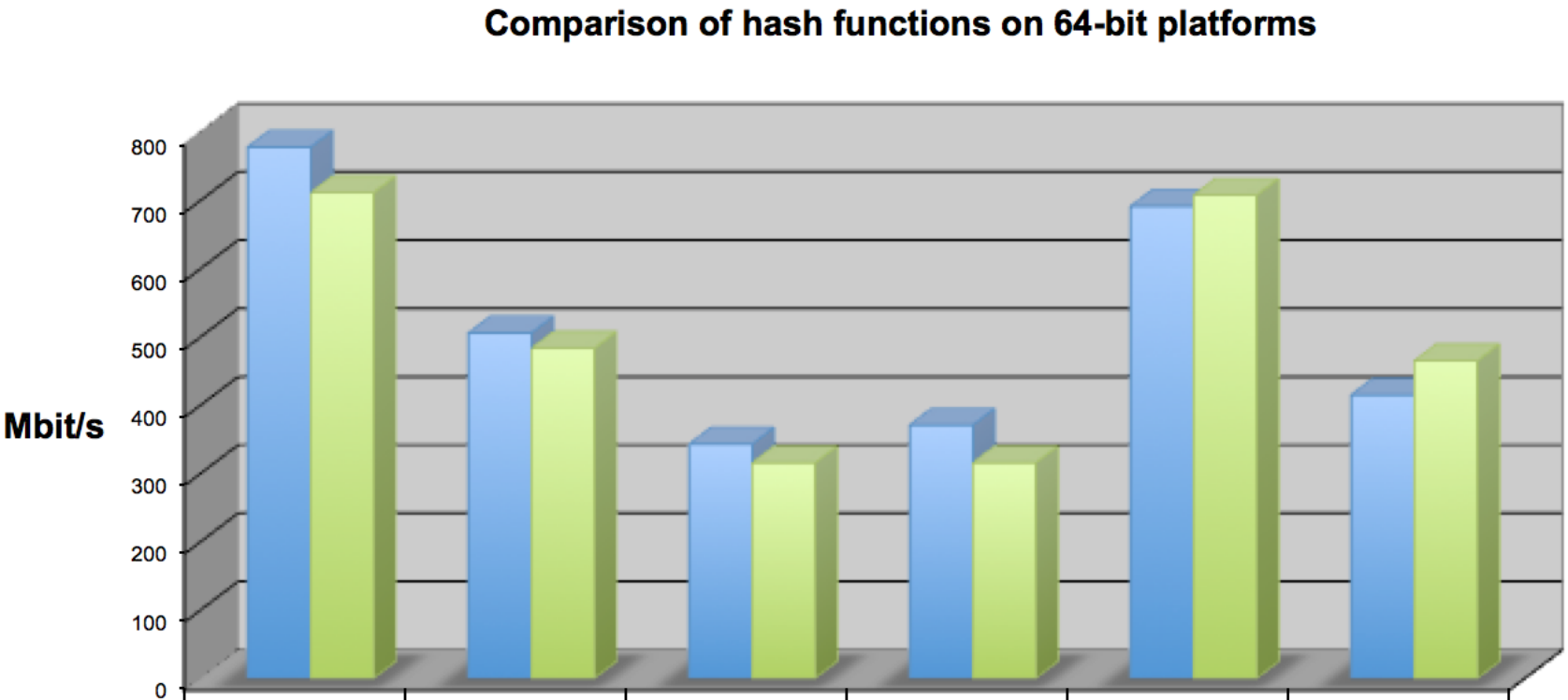
Kupyna is resistant to known cryptanalytic methods (based on public information)

Attack	Kupyna-256	Kupyna-512
Collision	2^{128}	2^{256}
First pre-image	2^{256}	2^{512}
Second pre-image	2^{256}	2^{512}
Fixed points	2^{256}	2^{512}
Length extension	2^{256}	2^{512}

The Ukraine standard DSTU 7564:2014

- based on the hash function Kupyna
  - the length of the hash value is flexible
  - predefined recommended parameters
- the message length can vary from 0 (the empty message) to $2^{96} - 1$ bits
- test vectors including not aligned to the block and byte length
- generating of MAC is defined as a mode of operation

Kupyna: performance comparison



	Kupyna-256	Kupyna-512	GOST 34.311-95	Stribog (256,512)	Groestl-256	Groestl-512
Linux 64-bit	778.3093	506.0145	343.2474	371.3182	691.6352	415.3906
Windows 64-bit	711.6397	483.6045	315.8514	316.0483	707.8276	465.3006

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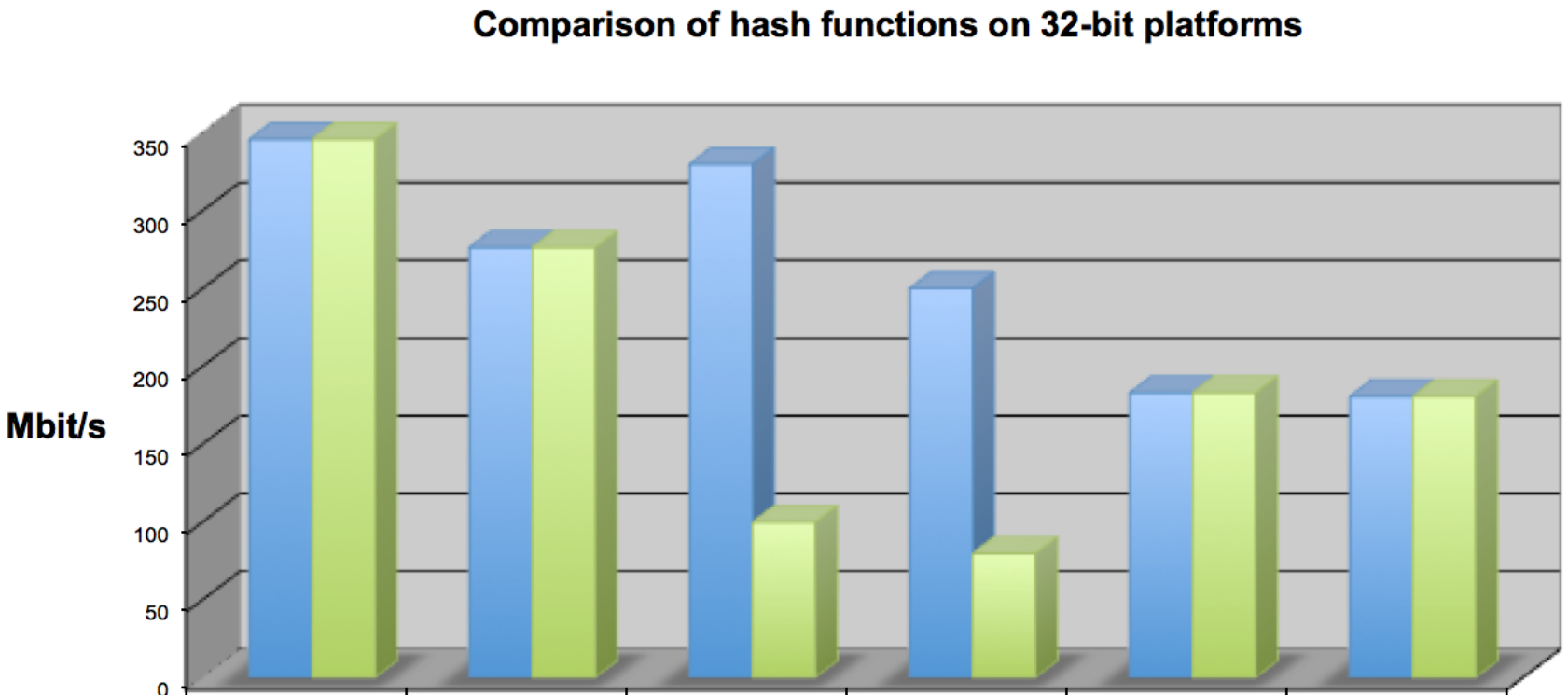

	Kupyna-256	Kupyna-512	GOST 34.311-95	Stribog (256,512)	Groestl-256	Groestl-512
Linux 32-bit	346.1454	276.6373	330.1143	250.2085	183.167	180.8638
Windows 32-bit	346.1454	276.6373	100	80	183.167	180.8638

Conclusions

The hash function Kupyna

- provides resistance to known cryptanalytic methods
- based on proven and transparent design principles
- generates hash values that meet the requirements for pseudorandom sequences (NIST STS)
- provides high performance on 64-bit and 32-bit platforms
- allows implement encryption algorithms effectively

Title

Figure: Kupyna / Polygonatum / Kantkonvall