Seamless Upgrades for Credential Security in Apache Tomcat

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* Slides available on the Linux Foundation / ApacheCon2017 web site and at http://people.apache.org/~schultz/ApacheCon NA 2017/Seamless Upgrades for Credential Security in Apache Tomcat.odp

Password Security Failures

- Lifeboat (Minecraft) (MD5)
- Ashley Madison (bcrypt.... but also MD5)[1]
- VTech (MD5)[2]
- LinkedIn (SHA-1)
- Pre-NT Microsoft Windows passwords (awful DES-based algorithm, 14 chars max, case-insensitive)[3,4]
- Microsoft Outlook (CRC32) [3]

1. http://arstechnica.com/security/2015/09/once-seen-as-bulletproof-11-million-ashley-madison-passwords-already-cracked/
2. https://www.theguardian.com/technology/2015/nov/30/vtech-toys-hack-private-data-parents-children
3. https://www.trustedsec.com/may-2015/passwordstorage/
4. https://en.wikipedia.org/wiki/LM_hash

Password Security Failures

- Dropbox (bcrypt, some still using SHA-1)[5]
- MySpace (SHA-1)[6]
- Yahoo! (bcrypt, and … ?)[7]

5. https://www.theguardian.com/technology/2016/aug/31/dropbox-hack-passwords-68m-data-breach
6. http://www.zdnet.com/article/myspace-hack-puts-another-427-million-passwords-up-for-sale/
7. https://www.theguardian.com/technology/2016/sep/23/yahoo-questinos-hack-researchers

Password Security Failures

- No credential security (plaintext/cleartext)
- Rolling your own security
  - Existing tools are inconvenient
  - NIH syndrome
- Using known poor or outdated algorithms
  - MD5, SHA1
- Using inappropriate algorithms
  - Simple hashes (e.g. MD[0-9], SHA-[1-9]+)

Password Security Failures

- Bad credential security means that users at risk, even when they aren't using your application
- Note that this is different than application security, where the service itself is at risk, not necessarily the users

What Exactly Are We Protecting?

- Only really protects the user database
  - Container protects the application from users
  - Application protects the data from users
- Mitigates an attack where the user database is stolen
  - Might have bigger problems on your hands
- User database is still important
  - May allow lateral attacks against other services
    - email, finance, medical records
  - Even admins shouldn't have users' passwords

What Exactly Are We Protecting?

- Think your user database won't be stolen?
- Just ask LinkedIn, eHarmony, and Last.fm
  - All hacked within a week in 2012
  - All had their user databases published

User Database Attacks

- User database contents
  - Username
  - Email address
  - Credentials (password)
- Username and/or email address may be valid elsewhere
  - Password might be valid elsewhere, too
- Compromise of one user database may allow access to other services

User Database Attacks

- Many users aren't very creative when it comes to setting passwords
  - 5up3rsecre7!
  - firstname2016
- Many users “know” that re-using passwords isn't a good idea
  - They use a “high-security” password only for high-security sites (e.g. bank)
  - What happens when your bank's user database gets hacked?

Attacking User Databases

- Cleartext
  - Trivial: password is right there
- Simple hashing algorithms (MD5, SHA1, SHA2)
  - Rainbow tables
  - Online services with massive hash databases
- Salted hashes
  - More difficult, often requires brute-force
- Key-derivation algorithms (PBKDF2, bcrypt)
  - Very difficult, usually requires brute-force

Determined Adversaries

- A quick note about a determined adversary
  - Well-funded and state-level adversaries have the computing resources to brute-force many algorithms
  - If your user database has been compromised, any individual user should be considered compromised
  - Which user? Who knows...
- Best strategy is to use the highest security available to you in all cases
  - Use a password-hashing algorithm

Key-Derivation Algorithms

- Difficult by design
  - Slow – many dependent operations
  - High memory requirements
- Compare to message-digest hashing algorithms
  - Very fast
  - Often implemented directly in hardware

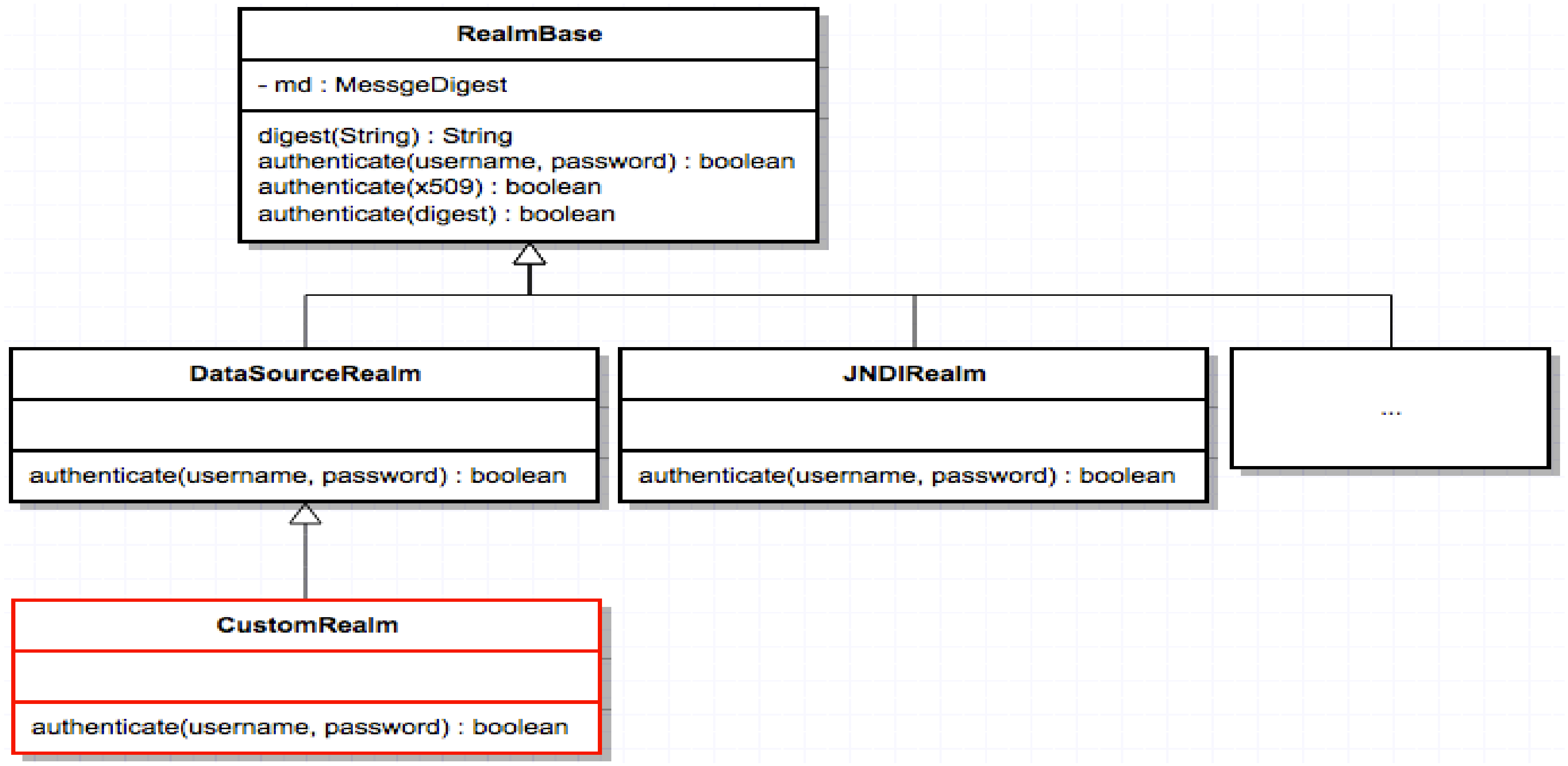
Key-Derivation Algorithms

- PBKDF2 (1991)
  - NIST standard
  - FIPS-140 compatible
  - No known weaknesses
- bcrypt
  - Open-source origin (1999)
  - Non-standard, based upon Blowfish cipher
  - Can be tuned to be arbitrarily expensive (iterations)
  - No known weaknesses

Historical Tomcat Support

- Tomcat has supported simple message-digest-based algorithms since at least Tomcat 3.x
  - Anything java.security.MessageDigest supported
  - No salting
  - No iterations
  - No 3rd-party plug-ins
- Using custom credential-manipulation code required a custom Realm
  - Realms must support lots of unrelated stuff

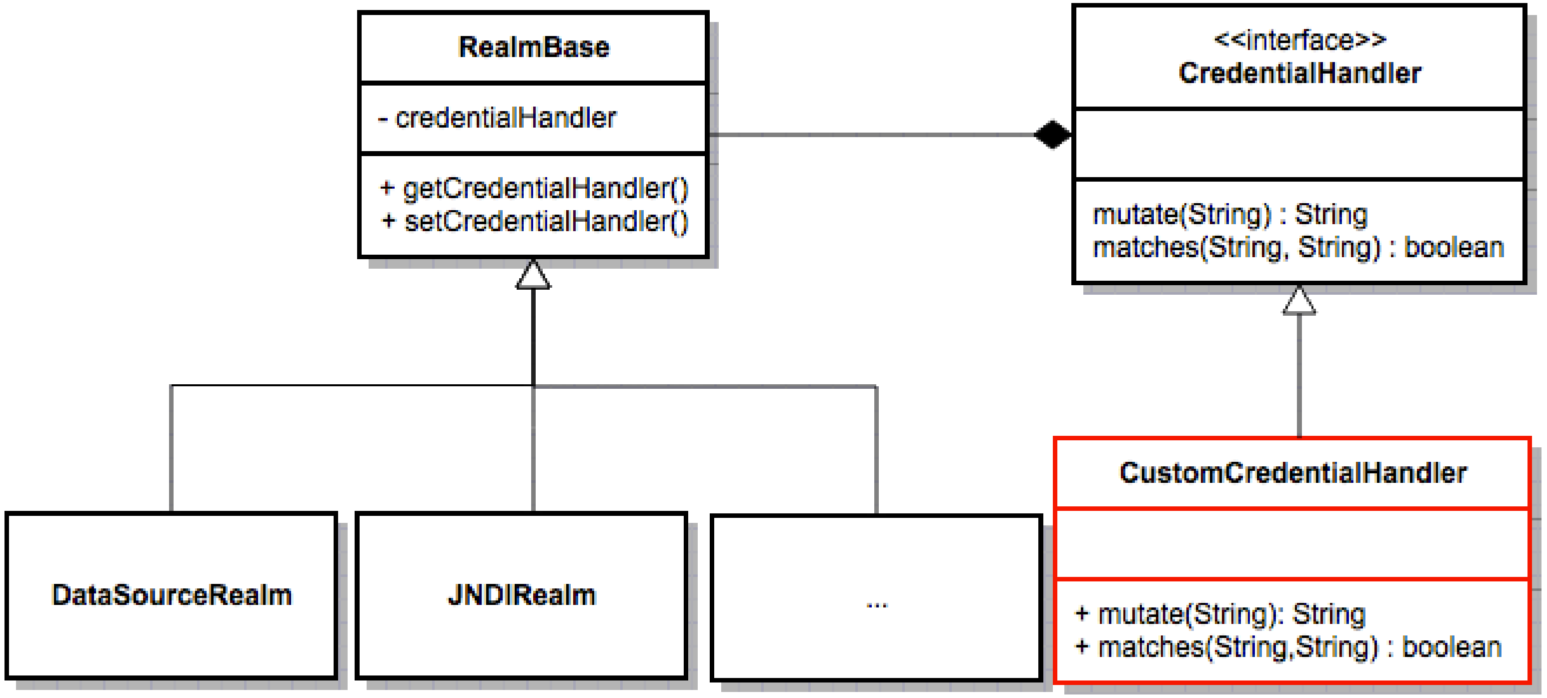
Historical Tomcat Support


RealmBase
- md : MessgeDigest
digest(String) : String
authenticate(username, password) : boolean
authenticate(x509) : boolean
authenticate(digest) : boolean
DataSourceRealm
authenticate(username, password) : boolean
JNDIRealm
authenticate(username, password) : boolean
...
CustomRealm
authenticate(username, password) : boolean

Modern Tomcat Support

- Still supports message-digest-based algorithms
  - java.security.MessageDigest
  - Backward-compatible
  - Adds salting and iterations if desired
- New pluggable CredentialHandler interface
  - Sky is the limit
- Included CredentialHandler implementation
  - PBKDF2 (if supported by JVM)
  - Good example for custom implementations

Modern Tomcat Support



Modern Tomcat Support

- Does not support other algorithms like bcrypt, etc.
  - Possible licensing issues, need to pick a vendor
  - Did not want compile-time dependency on 3rd-party library
  - Easy enough to plug-in, not a high-priority to include in Tomcat's distribution

Modern Tomcat Support

- Includes NestedCredentialHandler
  - Allows more than one CredentialHandler to be used
  - This allows for seamless upgrades between algorithms

CredentialHandlers

- Simple Java interface

```
public interface CredentialHandler {
    boolean matches(String inputCredentials,
                    String storedCredentials);
    String mutate(String inputCredentials);
}
```

- Easy to implement anything you want
- Interface can be used to mutate as well as validate
  - Can use directly in your applications

Using CredentialHandlers

- Easy to configure

```
<Realm
className="org.apache.catalina.realm.DataSourceRealm"...>
    <CredentialHandler
className="org.apache.catalina.realm.MessageDigestCredentia
lHandler" algorithm="MD5" />
</Realm>
```

- Above configuration is NOT RECOMMENDED
  - Uses insecure MD5 hashing algorithm

Using CredentialHandlers

- Easy to improve security

```
<Realm
className="org.apache.catalina.realm.DataSourceRealm"...>
    <CredentialHandler
className="org.apache.catalina.realm.MessageDigestCredentialHa
ndler" algorithm="MD5" saltLength=”16” iterations=”10000” />
</Realm>
```

- Above configuration is more secure than pure MD5
  - Uses salted passwords
  - Uses many MD5 iterations

Aside: Salted Hashes

- A “salt” is a nonce used to add randomness to something that is not random at all (i.e. passwords aren't random). A nonce is one-time use “word”.
- Stored salted passwords look different from each other even when the password is the same, since the nonce is different
- Example: password=`tiger`, salt=`982736549`
  salted password=`982736549tiger`
- System stores both the salt and the hashed salt+password as the credential
- This (usually) defeats rainbow table attacks

Using CredentialHandlers

- Easy to significantly improve security by using a key-derivation algorithm

```
<Realm
className="org.apache.catalina.realm.DataSourceRealm"...>
    <CredentialHandler
className="org.apache.catalina.realm.SecretKeyCredentialHan
dler" />
</Realm>
```

- Above configuration is very secure
  - Uses PBKDF2 algorithm (default)

Using CredentialHandlers

- Looks like great stuff
- But all my users have MD5-based passwords
- How is this relevant for me?

Upgrading CredentialHandlers

- Easy to migrate from one strategy to another

```
<Realm className="org.apache.catalina.realm.DataSourceRealm"...>
    <CredentialHandler
className="org.apache.catalina.realm.NestedCredentialHandler">
      <CredentialHandler
   className="org.apache.catalina.realm.SecretKeyCredentialHandler" />
      <CredentialHandler
  className="org.apache.catalina.realm.MessageDigestCredentialHandler"
     algorithm="MD5" />
  </CredentialHandler>
</Realm>
```

- Above configuration will support both systems
  - First tries PBKDF2
  - Falls-back to MD5

Upgrading CredentialHandlers

- Easy to migrate from one strategy to another

```
<Realm className="org.apache.catalina.realm.DataSourceRealm"...>
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```

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  - First tries PBKDF2
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It is ***vitally*** important not to configure plaintext as a fall-back!

Using CredentialHandlers

- Looks like great stuff
- But all my users have MD5-based passwords
- How can I get my users to change to something better?

CredentialHandlers in Webapps

- Tomcat makes the CredentialHandler available to applications through the application context*

```
CredentialHandler ch = (CredentialHandler)application
                              .getAttribute(Globals.CREDENTIAL_HANDLER);

String stored = ch.mutate(plaintext);

// update stored credentials in user database
```

- Applications can use Tomcat's API directly

* Since Tomcat 9.0/8.5, 8.0.34, and 7.0.70

CredentialHandlers in Webapps

- Use reflection if you don't want Tomcat as a build-time dependency
  - Avoid build-time dependencies via reflection

```
Class<?> globals = Class.forName("org.apache.catalina.Globals");
String attrName = (String)globals
              .getDeclaredField("CREDENTIAL_HANDLER").get(null);
Object ch = context.getAttribute(attrName);
Class<?> ich = Class.forName("org.apache.catalina.CredentialHandler");
Method mutateMethod = ich.getMethod("mutate", new Class[]
{ String.class} );

String stored = (String)mutateMethod.invoke(plaintext);
```

- Same effect with simpler dependencies

CredentialHandlers in Webapps

- Can also check existing credentials
  - Verify current password before update
  - Check password history

```
CredentialHandler ch = (CredentialHandler)application
                           .getAttribute(Globals.CREDENTIAL_HANDLER);

if(ch.matches(old_password, stored)) {
  // Allow update
} else {
  // Invalid current password! Veto profile update!
}
```

Custom CredentialHandlers

- Support currently-unsupported algorithms
- Don't roll your own security
- CredentialHandler should be plumbing code, not an algorithm implementation

Custom CredentialHandlers

- Support currently-unsupported algorithms
- Don't roll your own security
- CredentialHandler should be plumbing code, not an algorithm implementation
- Don't roll your own security

Custom CredentialHandler

- Let's implement bcrypt

Custom CredentialHandler: bcrypt

- Let's implement bcrypt
- Choose a Java implementation
  - http://www.mindrot.org/projects/jBCrypt/ (Ant fans)
  - https://github.com/jeremyh/jBCrypt (Maven fans)
- Understand the existing API
- Wire-into a simple CredentialHandler class

Custom CredentialHandler: bcrypt

- Implementation is trivial

```
public class BCryptCredentialHandler {
  public boolean matches(String inputCredentials, String storedCredentials) {
    return BCrypt.checkpw(inputCredentials, storedCredentials);
  }
  public String mutate(String inputCredentials) {
    return Bcrypt.hashpw(inputCredentials,
                         Bcrypt.gensalt(getLogRounds(), getRandom()));
  }
}
```

I've left out some support details like get/setLogRounds, and a SecureRandom member. Full implementation is available along with these slides online.

Custom CredentialHandler: bcrypt

- Configuration is trivial

```
<Realm
className="org.apache.catalina.realm.DataSourceRealm"...>
  <CredentialHandler
          className="my.package.BCryptCredentialHandler"
         logRounds=”12” />
</Realm>
```

- Tomcat handles calling our `setLogRounds` method
- Make sure your stored-password field can support the format (60 ASCII characters in this case)

Custom CredentialHandler: bcrypt

- Passwords are now stored in bcrypt format
  - `$2a$12$SGvTib1z7PiNihnOu7zJyuiq214MyQF/JdJEOgwuoziOOwUgDeqIi`
- Compare to MD5
  - `84da2a74e610e8029431a6540c07d66b`
- Compare to plaintext
  - `Tomcat is the best`

Custom Credential Handler

- bcrypt was easy to do
  - improves security of *stored credentials*
  - mitigates password-disclosure in case of database theft
- What else can we do with CredentialHandlers?
  - to improve security for *users*
  - to prevent unauthorized access to accounts

Custom Credential Handler

- Let’s implement two-factor authentication using TOTP

Custom Credential Handler

- Let’s implement two-factor authentication using TOTP
- ...on top of a decent password-based authentication system (PBKDF2)

Custom Credential Handler: TOTP

- TOTP: time-based one-time pad
  - Secret key shared once server → client
  - Client autonomously generates tokens based upon current time
  - Server independently generates the token for verification
  - No secrets travel the wire during authentication
  - Token can’t be intercepted unless TLS is broken (compare with SMS/email/etc. token delivery)

Custom Credential Handler: TOTP

- TOTP mobile apps
  - Google Authenticator
  - LastPass
  - Authy
  - Others
- RSA SecureID keys (well, not technically TOTP but very similar)

Custom Credential Handler: TOTP

- Plan for TOTP CredentialHandler
  - Use a delegate CredentialHandler for usual authentication
  - Prefix the user’s stored credential with TOTP shared secret and token to identify it as such

Custom Credential Handler: TOTP

- Example stored credential:
  - totp$[TOTP seed]$[delegate CH’s stored credential]
- Stored credential for password “test”, hashed with salted single-iteration SHA-256:
  - totp$tomcattomcattomcattomcat$ecf8e....285f68

Custom Credential Handler: TOTP

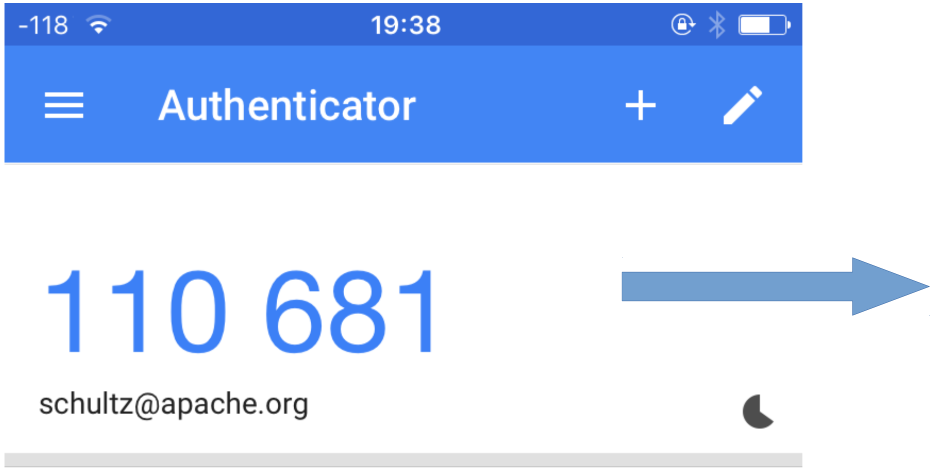
- Abridged code:

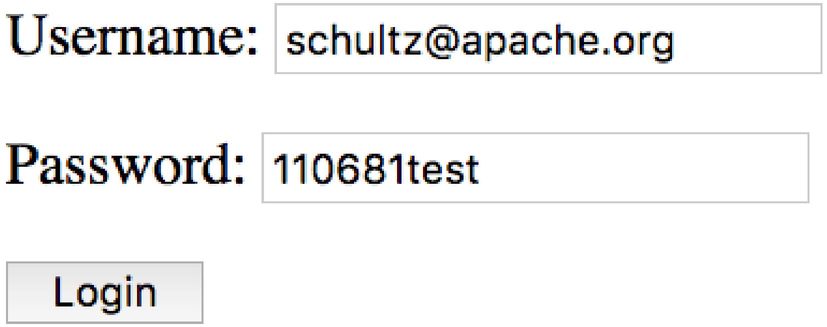
```
public boolean matches(String inputCredentials,
                       String storedCredentials) {
    int pos = storedCredentials.indexOf('$', totpPrefix.length());
    String totpSeed = storedCredentials.substring(totpPrefix.length(),
                                                  pos);
    String[] totpValidCodes = getTOTPValidCodes(totpSeed);

    for(int i=0; i<totpValidCodes.length; ++i)
        if(inputCredentials.startsWith(totpValidCodes[i]))
            // invoke delegate credential handler & return

    // TOTP does not match
    return false;
}
```

I've left out some significant details, here. Full implementation is available along with these slides online.

Custom Credential Handler: TOTP

- Login using username and token + password for password field




Username: schultz@apache.org

Password: 110681test

Tomcat Authentication

- Historically, Tomcat only supported MessageDigest-based credential security, and building a custom solution was cumbersome
- Recent Tomcat versions (since late 2014) support pluggable CredentialHandlers which significantly simplifies this process; support for better algorithms is now included with Tomcat

Tomcat Authentication

- Plugging-in new algorithms (e.g. bcrypt) is trivial
- Applications can access the CredentialHandlers directly if necessary
- Users' existing passwords can be migrated to higher-security storage schemes

Questions

Slides available on the Linux Foundation / ApacheCon2017 web site and at http://people.apache.org/~schultz/ApacheCon NA 2017/Seamless Upgrades for Credential Security in Apache Tomcat.odp

Sample code available in the same directory.