Release: 20230414

Topics we cover

- Introduction to encryption and PKI
- Authentication mechanisms
- Authorization
- Roles
- Encryption
- Auditing
- Additional security measures

This module has three exercises

Keys and PKI

Although this isn't specific to MongoDB - understanding PKI and certificates as a concept is important and helps to understand how MongoDB uses them.

Encryption

Encryption protects data using a cryptographic key

- Keys allow to lock and unlock things
- Specifically to convert data between readable (plaintext) and unreadable (ciphertext)

Two types of encryption keys:

- Symmetric
- Asymmetric

Symmetric Encryption

Symmetric encryption uses a single key to encrypt and decrypt

- Limited to encryptions and decryption only
- Can be very fast/efficient
- Anyone who has the key can decrypt the message

The more entities that need the key, the greater the risk of compromise

Symmetric encryption is the simplest of the two main types of encryption, and the oldest.

The key is typically a shared secret, but sometimes the method itself is the secret (e.g. Caesar cipher / ROT13).

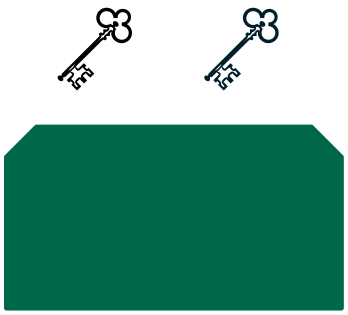
Asymmetric Encryption

Uses pair of encryption keys

- One private
- One public

Imagine a box with two keys

Whichever one is used to lock the box, the other unlocks



Asymmetric Encryption **(Public-Key Cryptography)** is much slower than Symmetric - but more versatile.

Public-key cryptography uses a key generation protocol (a mathematical function) to generate a key pair. Both the keys are mathematically related to each other in such a way that whichever one is used to encrypt data, the other one can decrypt it.

Think of a box where whichever key is used to lock the box, the other key unlocks the box.

One key in the pair (denoted the private key) is kept secret, the other (public key) is available to anyone who wants it.

Secure comms & verifying authenticity

Securely send to one recipient:

- Place item in box and lock with public key of the recipient
- Only the recipient's private key can open it

Verify authenticity

- Place item in box and lock it with owner's private key
- Magically copy box (its digital!)
- Everyone can open the box with the owner's public key and know it comes from the owner

Using a public-private key pair anyone can send things securely to one person.

Also one person can send to many, and they can be sure who it came from.

Certificates

A Certificate says

- Who we are
- Our public key
- When it's good until
- What we are allowed to do with it
- Who issued it and when

```
   Data:
        Version: 3 (0x2)
        Serial Number:

02:37:17:3a:ae:17:19:16:88:3d:0a:0f:0e:b8:7d:e7
    Signature Algorithm:
sha256WithRSAEncryption
        Issuer: C=US, O=Amazon, OU=Server CA
1B, CN=Amazon
        Validity
            Not Before: Jul 10 00:00:00 2020
GMT
            Not After : Aug 10 12:00:00 2021
GMT
        Subject: CN=www.mongodb.com
        Subject Public Key Info:
            [... big hex number … ]
            X509v3 Authority Key Identifier:

            X509v3 Subject Alternative Name:
                DNS:*.mongodb.com,
            X509v3 Key Usage: critical
                Digital Signature, Key
Encipherment
            X509v3 Extended Key Usage:
                TLS Web Server Authentication
```

A certificate contains the details about who we are and who the issuer was.
We can then look at the name on the certificate and see if it says they can do something (or are someone)
Starting from MongoDB 4.4 we check whether or not the authority has been revoked.

How can we trust a certificate?

It's signed - But how do I know the signature isn't fake?

- Is Signed by the person who holds it (self-signed)
- Created by someone we trust

How can we trust a certificate is genuine?
Like a paper certificate - anyone can print their own, so we need a way to verify that it was issued by someone qualified to certify them
We also need to know it's not been copied/stolen. Especially on it's way to the legal holder.

What is a signature?

Take the Certificate

Compute a Hash of the data - A Message Digest (MD in MD5)

Encrypt that MD with the private key

Now anyone who has the public key knows you approved it

Certificates come with an encrypted MD

- See who added the MD, get their public key
- Decrypt, compare to actual MD, check they match

Certificates can be signed - a signer computes a number (hash) from it then encrypts that hash
If we decrypt the number using the signatories key and it matches what we get when we hash it ourselves
Then it's correctly signed and has not been modified

How does this help trust?

The Certificate Authority (CA) is someone we all trust

We have their public key

They sign the certificate for the holder

They check the requester is the legitimate owner/holder

There is a chain-of-trust to the CA

We hold the CA Certificate (details and public key)

The role of the Certificate Authority is to act as the root of the chain of trust
They sign the certificates - having first ensured you have access to the domain you are asking for a certificate for
They might email at that domain, or ask you to host a specific file or create a DNS record.
They are often real world companies whose job it is to sign and notarise things

How do we get a certificate?

Complete a request (make an unsigned cert) - It includes:

- Who we are
- What we want to do
- Our public key

Example: Request to be a web server called *this.mongodb.com*

- Sign the request with our private key to prove we own the public key in it
- Send it to the CA – who digests it, encrypts it and signs it

What if it is intercepted on the way back from the CA?

- We hold on to our private key
- We give our cert to anyone who asks anyway
- It's our private key that matters if they want us to prove who we are

How to get a certificate:

- Complete a request using an unsigned certificate
- Send it to the CA
- CA signs and returns

Public Key Infrastructure

Understanding Encryption Keys and Public Key Infrastructure (PKI) is important

It's sometimes not well understood at this level

Don't need to know the maths behind how it works but helps understanding the basics

Certificate Authorities

There are top level CA's:
OS and Browsers know their public keys and trust them (Thawte & Verisign)

May issue certificates to be a CA for a specific subdomain – keep checking all way up:

- Host A is signed by CA 1 (who we don't know), but CA 1 uses a certificate that has CA rights and that certificate is signed by CA 2 (who we do know and trust)
- Only need a shared point of trust – can MAKE our own top CA – as long as we give out the CA certificate to anyone who has to trust it

Some companies whole business is being honest broker third parties
If they issue us a certificate - they have checked in the real world we are who we say we are
One permission they can give is permission to issue certificates, perhaps restricted in what for.
When using an intermediate CA to sign certificates we need to include the chain of certificates in our CA bundle when enabling TLS with MongoDB

Key Terms

Public Key
Private Key
Certificate Authority
CA Certificate
Intermediate Signing Certificate
Top Level Certificate Authority
Server Certificates
Client Certificates

Class Exercise

MongoDB Security

History of MongoDB security

Before 2017, Installing MongoDB on AWS was only:

```
sudo yum install mongodb
```

Can anyone see the problem this causes?

MongoDB has always had security - we just didn't enforce its use - which meant a lot of people never thought about it.
Now MongoDB makes us at least think about it and warns us if we are insecure.
MongoDB Atlas is always secure.

Security in MongoDB

Authentication
Authorization
Views
Transport Encryption
Encryption-at-Rest
Field-Level Encryption
Auditing
Log Redaction
Network Restrictions

There are different concepts of security to understand with MDB

Authentication

Authentication is proving you are who

By proving one or more factors:

- Something you know - like a password
- Something you have - like a certificate
- Something you are - like Biometrics, or an incoming IP address

MongoDB Authentication

SCRAM-SHA: Salted Challenge Response using Username and Password

X.509: Certificates to prove identity

LDAP: Authenticate against Active Directory/OpenLDAP

Kerberos: Authenticate with short-lived tokens/tickets

MONGODB-AWS (Atlas Only): Authenticate using Amazon Web Services IAM roles

MongoDB supports multiple authentication mechanisms - the main ones are listed here.
None of these are really appropriate for application-level users (users of an application or website) - database users should be for admins and services.

SCRAM-SHA

- MongoDB holds the Username & salted password hash
- Client does not send the password to the server on login
- Client requests a unique value (nonce) from server
  - Server sends back
  - Client hashes password, adds value hashes again
  - Client sends to server
  - Server adds value to password hash and hashes
- One round of hashes on Client, Two on Server
- Hash rounds are deliberately really slow and expensive – why?
- After login, connection remains authenticated

A round of hashes is 10 or 15 thousand hashes, logins are deliberately slow and CPU intensive to avoid brute force attacks.
This is important to know, we must only log in when we have to - create a single MongoClient object in applications not one per database call or web service call.
MongoClient has a connection pool and is thread safe.

SCRAM-SHA – Pros and Cons

Pros

- Simple
- Easy to understand
- Secure

Cons

- Manage separately for each database cluster
- Authorization is local (added responsibility)
- What if the passwords become known by people?
- How to secure passwords for service users (i.e. the application)?

X.509 Certificate

X.509 Certificate presented by Client (as part of TLS connection)

- MongoDB checks user DB to see if it knows and trusts that certificate
- The certificate file includes private key but that is not sent to the server – when client asks to login and hands over public, server then gives it something to sign with private to verify.
- Private key may have a password too to be typed in on client
- Sometimes the certificate needs to be in a client end key store

When logging into MongoDB via X.509 we need a PEM file that includes both the certificate and the private key, similar to what the MongoD instances use.

X.509 Certificate – Pros and Cons

Pros

- Can centrally provision credentials
- Can have a revocation list (revoked certificates) or OCSP

Cons

- Need a separate mechanism for Authorization like LDAP or Local
- Certificates need a password to be secure - Still need a password store

LDAP

Federate out authentication to Active Directory/LDAP

- Username and Password verified by AD server
- Can enforce password complexity/expiry
- Database relies on availability of AD to enable login though
- Uses plaintext credentials when verifying the user - Configure LDAP always with TLS to protect credentials on-the-wire (network encryption)

LDAP - Pros and Cons

Pros

- Common in organizations
- Allows users to log in with the same password they use for their desktop
- Single mechanism for Authentication and Authorization
- Easy to add or remove users from all databases

Cons

- Relies on the AD server being up
- Supports alternate servers
- Configuration requires an understanding of the LDAP Tree
- Requires TLS connection to LDAP to be secure

Kerberos

Well regarded and proven

Similar to X.509

- However new tickets (certs) are requested frequently
- Users log in to a Kerberos server to get a ticket that is used to log into MongoDB*
- Needs Kerberos Infrastructure set up to use it

*This is simplified description - a full explanation of Kerberos is out of the scope of this training.

Kerberos - Pros and Cons

Pros

- Well respected security technology
- Included in Active Directory
- Allows Windows users to login without a password
- Passes their windows identity over
- Good for Services as no need to store passwords

Cons

- Requires a mechanism to get Authorization such as LDAP
- Requires users to be explicitly identified in the local instance

With Kerberos we can also use MongoDB's local Role-based access control.

What to use and when?

Human users

- Should always have individual logins
- Centralized Identity Management (LDAP/Kerberos) is preferable
- SCRAM-SHA is secure but not centralized, requires more maintenance
- X.509 needs certificates with passwords and either local or LDAP Authorization

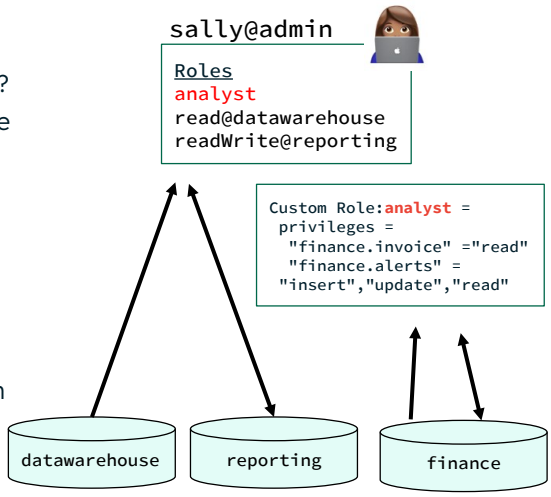
Software/Service users

- No human should know the credentials used by a service
- Kerberos is a great option for Windows Services
- On Atlas with AWS, IAM is available
- Can generate a random password (and associated user) at install time
- Store passwords securely at the application end (i.e, in an Enterprise Password MS)

Authorization (AUTHZ)

Authorization is what are you allowed to do?

- Users defined by username@database
- Database should always be 'admin'
- Users have 1 or more Roles
  - Built-in roles or custom roles
  - Roles can 'inherit' from others
  - Database roles or Atlas roles
- Roles include 1 or more privileges - A privilege means a user can perform an actions on a resource



Historically you could create a user database anywhere in MongoDB - nowadays this is deprecated and users should be managed in the admin database.
Sally is not an admin - she works as an analyst. Sally@admin is her username because every user is @admin (With some special exceptions)
Sally analyses historic data and looks for invoices which might be problematic - like not being paid, she flags these for the finance team.
She also creates reports on what she has discovered.
She has three roles: two built-in roles allowing her to read the datawarehosue and read and write to reporting.
She also has a custom role "analyst" which lets her read invoices in the finance databases and modify just the 'alerts' collection in the finance database.

When creating a custom role you can base it on a built in role or a custom role in the same database and inherit the permissions of parent roles.

Database resources

- Databases
- Collections
- Cluster
- Users

We describe the parts of the system as Resources - for example a Collection or a Cluster is an example of a Resource. Documents are not considered to be resources.

Database actions

- CRUD
- Database management
- Deployment management actions
- Replication actions
- Sharding actions
- Server administration actions
- Diagnostic retrieval actions

There are many type of action - these are just categories. A Role defines what actions a user can perform on what resources.

Database built-in roles

- dbAdmin
- clusterAdmin
- userAdminAnyDatabase
- readAnyDatabase
- readWriteAnyDatabase
- clusterMonitor
- read
- readWrite
- backup
- root

Atlas users get a subset as some admin actions cannot be performed on Atlas

Note that in MongoDB we separate out the core abilities to Manage Users, Manage the Clusters, Manage Data and Read/Write data into separate roles. Our DBA role neither gives Read permissions nor Shutdown permissions for example.

Atlas user privileges

- Atlas admin
- Read and write to any database
- Only Read Any Database
- Custom Roles - Make more specific access for the user

Atlas provides a more restricted set of roles. As an example, the users cannot shut down an Atlas host or change key parameters it is running with from inside MongoDB.

Scope of Authorization

User with **root** or **__system** roles can do everything

Three types of admins - Some admin roles cannot read data!

Down to a user who can do one action on one resource

Example, read-only on a single collection

MongoDB recommend not using root but instead giving superusers a set of roles like dbAdminAnyDatabase and userAdmin. It may be worthwhile having a root user but with a password locked away for emergency access.

Avoid using use the internal __system user unless advised by MongoDB support.

The three types of admins are:

1. Data Admins
2. User Admins
3. Cluster Admins

Document Level Security Options

Roles restrict down to Collection/View level- How to get Document level security?

Application Level

- Uses a single database user
- Application server determines what a user can see and do
- Most common approach of having a database user per customer seems wrong

Using Views

- Can create views that give a redacted view of the data
- Difficult to index well depending on the definition
- Good choice for data-masking in API's or BI Users

Using Atlas App Services

- Atlas App Services manages application users
- Provides rules or function based, field level security

Views work well when limiting the visible fields, if we also use them to limit the visible records we need to ensure our indexes cover both the filtering and the users query.

Defining Authorization

Authorization can define it as part of the user record in system.users -Normally used with SCRAM/KRB5/X.509

Can use LDAP (with any authentication except SCRAM-SHA)

- Configure to query LDAP for a list of 'group names'
- Can have each one be a role given to the user - Roles still need to be defined

In Atlas, you can use the GUI or an API call to set up permissions

Authorization best practices

Give minimum required rights to people - a.k.a Principle of least privilege (PoLP)
Minimum required rights to service accounts (i.e, Don't let them make indexes)
Make read only services have read only permissions
Create roles and users only on the "admin" DB
Avoid using use root/__system

- Have a root break-glass user if needed
- Not required with Atlas as can reset passwords from the GUI

Historically Users could be defined anywhere, not only in the admin DB (this feature is deprecated now)

Encryption

On the Wire (Network)

At Rest (Disk)

In Use (Client)

Network encryption

MongoDB supports TLS (mandatory or optional)

- requireTLS - Client **must** use TLS
- preferTLS - Clients 'may use TLS, replication will use TLS if possible'
- allowTLS - Client may use TLS
- disabled - Server does not support TLS

MongoDB servers can optionally require client certificates

- Can optionally provide X.509 Authentication
- Is good practice
- Requiring certificates when not using X.509 Auth may be excessive in many cases

Always use Network Encryption when possible (Default in Atlas and cannot be disabled)

The optional TLS configuration in MongoDB potentially allows transitioning a non-TLS Cluster to a TLS Cluster without downtime.

TLS 1.0 connections are disabled if the system supports TLS 1.1+. Specific TLS version numbers can be disabled using the net.tls.disabledProtocols configuration option. See https://www.mongodb.com/docs/manual/reference/configuration-options/#mongodb-setting-net.tls.disabledProtocols

Encryption at rest

With Encryption at rest, MongoDB encrypts the files on disk

Needs a secure way to store and manage the decryption keys

- Needs an external KMIP Key Vault
- Storing Keys locally is not considered secure
- MongoDB will automatically rotate keys if using a Key Vault

Encryption at rest protects us from the theft of files/disks

- Does not protect us from anyone who has gained access to the machine
- Does not protect us from theft of files if they also take the key
- Alternative to using encrypted disk volumes if we don't have them available to us

Encryption in Use - Field Level Encryption

Very relevant for developers

Individual fields are encrypted/decrypted at the client end

Required to be incorporated into application

Provides an additional layer of security

Keys still have to be kept safe

Note: Field level encryption does not get away from the requirement to have a place to keep the keys safe.

Encryption in Use - Field Level Encryption

Encryption in use secures against:

Data not being encrypted in cache - dumping RAM

A DBA/Admin being able to read data in the database

A root level hacker who restarts the database without security

Access to data by hosting/cloud provider - for example Atlas

Encrypt and Decrypt at the Client

Using Field Level Encryption

- Server never has cleartext data
- Server never has decryption keys
- Server side can never read unencrypted data

Client obtains key from a key management system

Client encrypts and decrypts specific fields as needed (SSN, Credit Card, Name)

Client only sends encrypted data or queries with encrypted values to server

Field Level Encryption modes

Free MongoDB Community

- Encryption function exposed in driver – encryption done manually by code record.name=encrypt(name)

Enterprise & Atlas

- JSONSchema defines encrypted fields
- Driver automatically encrypts CRUD operations including queries

One can combine these two approaches

Implementing Encryption is hard - MongoDB provides a secure and easy to use option

FLE Keys and Encryption

Driver has various options for storing client side keys

- Local keys/Hard coded keys
- Encrypted KeyVault on the server
- Using a third party KMS (AWS, Azure, GCP) for Master Keys for the vault

Driver uses Deterministic or Random Encryption

- **Deterministic**: value always encrypts to same encrypted value
  - Makes some analysis possible on data
  - Allows speculative querying
  - Can query fields and use indexes
- **Random** does not allow for queries to be performed on encrypted fields as data is stored differently each time

Server can store all the decryption keys, encrypted with a master key on the client so the client end only needs to find a safe way to store one key.
If a field is randomly encrypted - we cannot query it as it could have any value in the data so there is no way to turn the query term into a single value to search for. With deterministic then we encrypt the query term and search for the encrypted version which is the same everywhere.

Auditing

Auditing for security:

- Needs to record human intent
- Is a tool to protect employees rather than to catch criminals
- Not a debugging tool

Auditing the DB operations of an application:

- Is not auditing what a user did
- Is auditing what an application did to service request

Example: A query that fetches the first 100 results by default - don't know if the user viewed one or all of them

Auditing should only audit ad-hoc activity by DBA's and those with DB level access

Auditing is there so in the event of an incident you can see what your employees who have direct database access did, or important what they did not do - it's not a tripwire to see who is trying to perform tasks that security does not allow them to.
Auditing the behaviour of an application / service account is rarely useful, the application should audit what it's users are trying to achieve.
For debugging - often the OpLog (Database Transaction Log) is a good place to see what actually happened.

Security as a whole should be handled using **Security Information and Event Management (SIEM)** tools and services offering a holistic view of an organization's information security. SIEM tools provide: Real-time visibility across an organization's information security systems not just MongoDB - The Audit trail may flow into that.

MongoDB audit capability

- Can record all successful or prevented operations
- Only audits where security prevents a non-CRUD activity by default
  - Why audit where security stopped a thing? Is that useful?
- Auditing flushes disk before each operation
  - Only audit valuable ad-hoc information
  - Do not audit 'Business as Usual'
- Audit writes can be filtered by user/time/operation etc. as a MongoDB query
- Audit file can be JSON or BSON and goes on the local disk

Audit best practices

Have separate individual database logins for humans (DBAs)

- Audit everything done ad-hoc by a human
- Audit nothing done by a non-human
- Have service accounts that humans cannot use

Additional Security Features

Redacting PII from debug logs is hard - MongoDB has a flag to do it for us at write time

Listens only on localhost by default - Change that to make it listen on a real address

Can authorize incoming IP's (CIDRs) for individual users

You can redact entries in MongoDB logging for any PII or other values using the flag `redactClientLogData`
You can choose what IP Addresses mongodb listens on with the `bindIp` or `bindIpAll` config parameters
When creating a user you can configure what addresses they can access from using the `authenticationRestrictions` `clientSource` and `serverAddress` in the user record.

Internal Authentication

In a secure cluster, nodes communicate using the same port and protocol as humans

Each node logs into the others using either SCRAM-SHA or X.509

- With SCRAM-SHA, there is a shared secret in a file called keyfile - the user it connect as is __system@local
- With X.509, the certificate must have exactly the same Organisation and Organisation Units and a CN matching the hostname

When we have multiple servers that need to be able to connect to each other and trust each other - they use essentially the same login mechanisms as a human or application logging in.

If we are not using TLS then the login is always done using an internal user called __system@local with their credentials held in a file called the Keyfile supplied to each instance. Keyfile is normally a long random
set of base64 characters.

If we are using TLS and we ensure that each hosts TLS certificate has exactly the same Org and Org units then the hosts can connect and authenticate via X.509 if suitably configured.

If you enable Security in a Replica set or sharded cluster, keyfile internal authentication is enabled by default. System security can be enhanced further by using X.509 internal Authentication.

What about SQL Injection?

Because of BSON

- Injection attacks are not a thing at the DB level like they are in SQL
- MongoDB never parses Text or JSON on the server

However because of JavaScript Browsers/Apps and Node.js

- Client side Javascript injection IS still possible
- Be careful not to evaluate things entered by users

```
n = readUserInputString()
query = JSON.parse("{name:"+n+"}") // BAD what if n is {$ne:"x"}
query = {"name":n } // Safer but what if n = null
query = {"name": `${n}` } // Safe because `${n}` converts all values to string
```

With SQL bad code combines input with a query to make SQL. This can be used to break security.
input name:

Query = "select * from users where name=${NAME}"
db.execute(Query)

If name is " 'BOB' OR 1 = 1" it will fetch all records. or worse "BOB; DROP TABLE USERS"

Quiz Time!

#1. Which of the following are features of MongoDB Security?

A	Authentication	B	Authorization	C	Network Encryption
D	Encryption at Rest	E	Auditing		

Answer in the next slide.

#1. Which of the following are features of MongoDB Security?

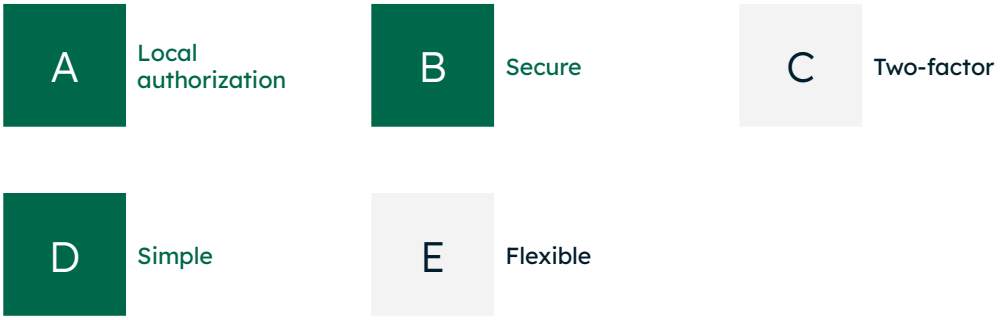
Answer: A, B, C, D, E

#2. What words accurately describe SCRAM-SHA256 authentication?

A	Local authorization	B	Secure	C	Two-factor
D	Simple	E	Flexible		

Answer in the next slide.

#2. What words accurately describe SCRAM-SHA256 authentication?



Answer: A, B, D

#3. When working with Field level encryption, which of these are true?

A	The Database Administrator can still see all the data	B	Encrypted data can be queried	C	Encrypted data can be indexed
D	The server holds the master keys for the encryption securely	E	MongoDB can automatically encrypt values for you on the fly		

Answer in the next slide.

#3. When working with Field level encryption, which of these are true?

A	The Database Administrator can still see all the data	B	Encrypted data can be queried	C	Encrypted data can be indexed
D	The server holds the master keys for the encryption securely	E	MongoDB can automatically encrypt values for you on the fly		

Answer: B, C

Recap

Keys are used to encrypt and decrypt data

Asymmetric keys allow us to know who encrypted an item of data

MongoDB has a rich set of security mechanisms

Security requires more than just database controls

If everyone knows a password then security is broken

Field Level Encryption allows us to trust strangers to mind our data