
SBA
Research

Typed Security

Preventing vulnerabilities by design

sec4dev – 2022-09-09

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OPEN INNOVATIONS

$ whoami

- Michael Koppmann
- Penetration tester at SBA Research
- Software engineer
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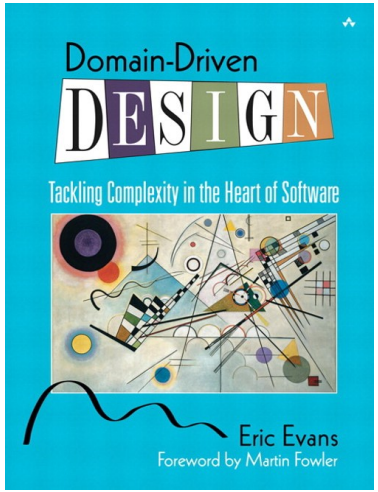
Domain-Driven Design (DDD)



- Primary focus on core domain and business logic
- Iteratively refine concepts by consulting domain experts
- Uses ubiquitous language that everyone in the domain understands
- Popular concepts: Entities, Value Objects, Aggregates, Bounded Contexts, Repositories

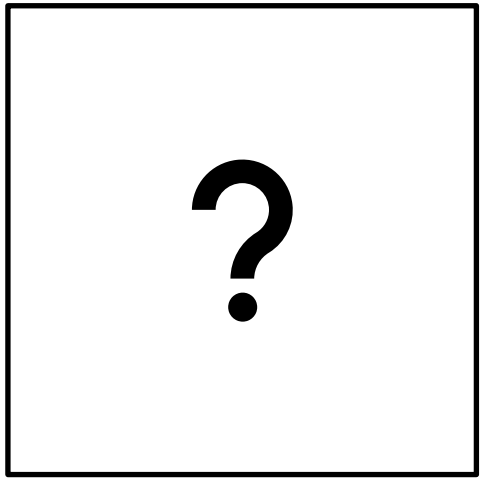
Type-Driven Domain Design

- Encode business rules into types
- Make illegal state unrepresentable
- Prevent security vulnerabilities
- Immutability avoids doing the same checks over and over again
- Offload work to the compiler

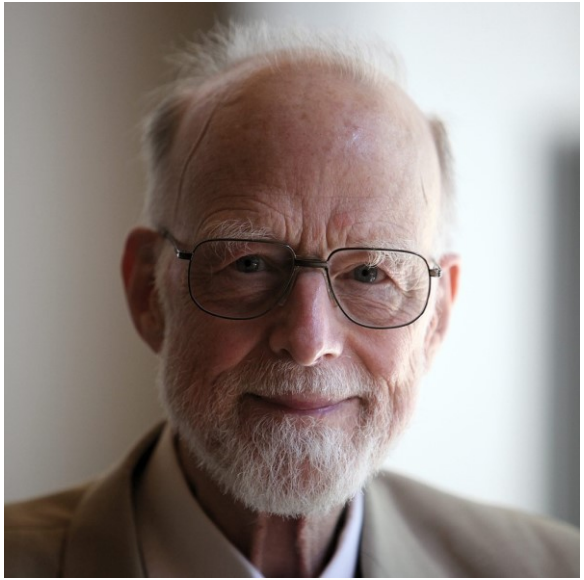
Language Support

- Any language can be used for DDD
- But some provide more powerful type systems
- Nice to have: Sum Types (Tagged Unions), Pattern Matching
- Examples:
  - Haskell
  - Elm
  - OCaml
  - F#
  - Rust
  - Scala
  - ReScript
  - TypeScript
  - C# (7)
  - Java (17)

Null



Null



"I call it my billion-dollar mistake. It was the invention of the null reference in 1965."
Tony Hoare

Source: https://commons.wikimedia.org/wiki/File:Sir_Tony_Hoare_IMG_5125.jpg

Make the Absence of Values Explicit (Java)

```java
Optional<String> lookup(String key, Map<String, String> map) {
  String value = map.get(key);
  return Optional.ofNullable(value);
}

String getContactDescriptionOrDefault(String name,
                                      Map<String, String> phonebook) {
  Optional<String> opt = lookup(name, phonebook);
  return opt.map(number -> name + "'s number is: " + number)
            .orElse("Could not find a number for " + name);
}
```

The Problem With Basic Data Types

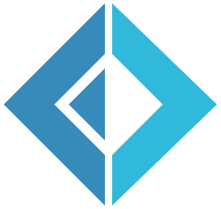
- Relying on them too much is an anti-pattern called “Primitive Obsession”
- No enforcement of constraints
- Any manipulation could invalidate the invariants of the data

Never Mix Up IDs Anymore (C#)

```
1.  public readonly record struct UserId(Guid Id)
2.  {
3.      public override string ToString() => Id.ToString();
4.      public static implicit operator Guid(UserId userId) => userId.Id;
5.  }

6.  void StorePaymentForUser(PaymentId paymentId, UserId userId) { ... }

7.  Service.StorePaymentForUser(userId, paymentId); // COMPILER ERROR!
```

Modeling a Contact Type

Because not everything is a string



```
type Contact =
    {
        FirstName: string;
        Initial: string;
        LastName: string;

        EmailAddress: string;
        // true if verification mail was confirmed
        IsEmailVerified: bool;
    }
```

```
type PersonalName =
    {
        FirstName: string;
        Initial: string;
        LastName: string;
    }

type EmailContactInfo =
    {
        EmailAddress: string;
        IsEmailVerified: bool;
    }

type Contact =
    {
        Name: PersonalName;
        EmailContactInfo: EmailContactInfo;
    }
```

```
1. let EmailAddress = private EmailAddress of string

2. module EmailAddress =

3.     let create (input: string) =
4.         if System.Text.RegularExpressions.Regex.IsMatch(input, @"^\S+@\S+\.\S+$")
5.             then Some (EmailAddress input)
6.             else None

7.     let value (EmailAddress address) = address
```

```
type PersonalName =
    {
        FirstName: String50;
        Initial: String1 option;
        LastName: String50;
    }

type EmailContactInfo =
    {
        EmailAddress: EmailAddress;
        IsEmailVerified: bool;
    }

type Contact =
    {
        Name: PersonalName;
        EmailContactInfo: EmailContactInfo;
    }
```

```
type EmailContactInfo =
    | Unverified of EmailAddress
    | Verified of VerifiedEmailAddress

let EmailAddress = EmailAddress of string
let VerifiedEmailAddress = private VerifiedEmailAddress of string

module EmailVerification =

    let storeVerificationCode (contact: EmailContactInfo, code: VerificationCode) =
        match contact with
        | Verified -> ()
        | Unverified (EmailAddress addr) ->
            // store verification code in the DB for email address.

    let verify (contact: EmailContactInfo, code: VerificationCode) =
        match contact with
        | Verified -> Some contact
        | Unverified (EmailAddress addr) ->
            // check if given verification code matches code
            // stored in DB for this mail address
            Some (VerifiedEmailAddress addr)

    let value (VerifiedEmailAddress address) = address
```

```
1. type Contact =
2.     {
3.         Name: PersonalName;
4.         EmailContactInfo: EmailContactInfo;
5.     }

6. type SendPasswordResetEmail = VerifiedEmailAddress -> ...
7. type ChangeEmail = String -> ... -> EmailContactInfo
8.     // creates new email contact with Unverified constructor
```

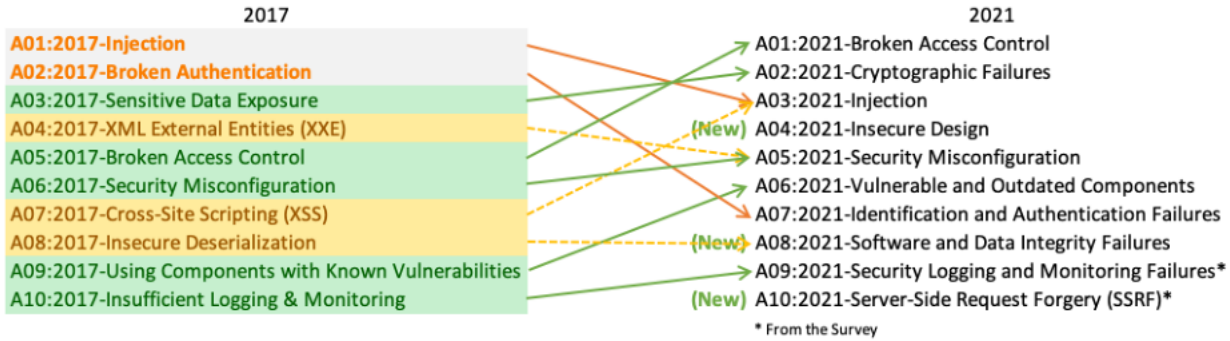
Tackling the OWASP Top Ten

At least some of them.

Types don’t solve all your problems ;)

OWASP Top Ten (2021)

- A01:2021-Broken Access Control
- A03:2021-Injection
- A04:2021-Insecure Design



OWASP API Security Top 10 (2019)

- API1:2019 Broken Object Level Authorization
- API3:2019 Excessive Data Exposure
- API5:2019 Broken Function Level Authorization
- API6:2019 Mass Assignment
- API8:2019 Injection

Types For Authorization

Fighting broken access control attacks

```
1.  Web.get "/articles/:id" $ do
2.    curUser   <- AuthN.getUser
3.    articleId <- param "id"
4.    if not (AuthZ.canAccessArticle curUser articleId)
5.      then Web.status 401
6.      else do
7.        article <- Service.getArticle articleId
8.        Web.json (toViewModel article)
```

```
1.  Web.delete "/articles/:id" $ do
2.    curUser   <- AuthN.getUser
3.    articleId <- param "id"
4.    if (AuthZ.canModifyArticle curUser articleId)
5.      then Web.status 401
6.      else do
7.        Service.deleteArticle articleId
8.        Web.status 204
```

```
1.  Web.put "/articles/:id" $ do
2.    curUser     <- AuthN.getUser
3.    articleId   <- param "id"
4.    articleData <- param "data"
5.    if not (AuthZ.canModifyArticle curUser articleId)
6.      then Web.status 401
7.      else do
8.        Service.putArticle articleId articleData
9.        Web.status 204
```

1.

```
canAccessArticle :: User -> Id Article -> Bool
canAccessArticle user articleId = ...

canModifyArticle :: User -> Id Article -> Bool
canModifyArticle user articleId = ...
```

2.

```
newtype AccessArticle = AccessArticle (Id Article)
newtype ModifyArticle = ModifyArticle (Id Article)

newtype AccessToken a = AccessToken a

tokenData :: AccessToken a -> a
tokenData (AccessToken data) = data
```

3.

```
getAccessArticleToken :: User -> Id Article -> Maybe
(AccessToken AccessArticle)
getAccessArticleToken user articleId =
  if canAccessArticle user articleId
    then Just (AccessToken (AccessArticle articleId))
    else Nothing

getModifyArticleToken :: User -> Id Article -> Maybe
(AccessToken ModifyArticle)
getModifyArticleToken user articleId =
  if canModifyArticle user articleId
    then Just (AccessToken (ModifyArticle articleId))
    else Nothing
```

4.

```
module Authorization
  ( AccessToken
  , tokenData
  , AccessArticle (..)
  , ModifyArticle (..)
  , getAccessArticleToken
  , getModifyArticleToken
  )
where
```

```haskell
getArticle :: AccessToken AccessArticle -> IO Article
getArticle token = do
  let (AccessArticle articleId) = tokenData token
  Db.fetchArticle articleId

putArticle :: AccessToken ModifyArticle -> Article -> IO ()
putArticle token articleData = do
  let (ModifyArticle articleId) = tokenData token
  Db.putArticle articleId articleData

deleteArticle :: AccessToken ModifyArticle -> IO ()
deleteArticle token = do
  let (ModifyArticle articleId) = tokenData token
  Db.deleteArticle articleId
```

```
1.  Web.get "/articles/:id" $ do
2.    curUser   <- AuthN.getUser
3.    articleId <- param "id"
4.    case AuthZ.getAccessArticleToken curUser articleId of
5.      Nothing    -> Web.status 401
6.      Just token -> do
7.        article <- Service.getArticle token
8.        Web.json (toViewModel article)
```

```
1.  Web.delete "/articles/:id" $ do
2.    curUser   <- AuthN.getUser
3.    articleId <- param "id"
4.    case AuthZ.getModifyArticleToken curUser articleId of
5.      Nothing    -> Web.status 401
6.      Just token -> do
7.        Service.deleteArticle token
8.        Web.status 204
```

```
1.  Web.put "/articles/:id" $ do
2.    curUser     <- AuthN.getUser
3.    articleId   <- param "id"
4.    articleData <- param "data"
5.    case AuthZ.getModifyArticleToken curUser articleId of
6.      Nothing    -> Web.status 401
7.      Just token -> do
8.        Service.putArticle token articleData
9.        Web.status 204
```

Fighting Injection Attacks (Haskell)

```
1.  import qualified Database.SQLite.Simple as SQL

2.  main = SQL.withConnection "products.db" $ \conn -> do
3.      putStrLn "Search by product name:"
4.      pname    <- getLine
5.      products <- getProductsByName conn pname
6.      putStrLn ("Here is the data: " ++ show products)

7.  -- SQL.query :: SQL.Connection -> SQL.Query -> args -> IO [result]

8.  getProductsByName :: SQL.Connection -> String -> IO [Product]
9.  getProductsByName conn pname =
10.     SQL.query conn (SQL.Query "SELECT * FROM products WHERE product_name=?") (pname)
```

Fighting Excessive Data Exposure (Java)

```java
public class User {
    private final Id<User> id;
    private Name50 firstName, lastName;
    private Birthdate dateOfBirth;
    private PasswordHash passwordHash;
    // Constructor, getters, setters, domain logic, etc.
}
public class UserViewModel {
    private final String fullName;
    private final DateTime dateOfBirth;
    // Constructor, getters, mapping from entity to dto and vice versa
}
public List<UserViewModel> getUsers(...) {
    List<User> users = userService.getUsers(...);
    return users.stream().map(UserViewModel::entityToViewModel).collect(Collectors.toList());
}
```

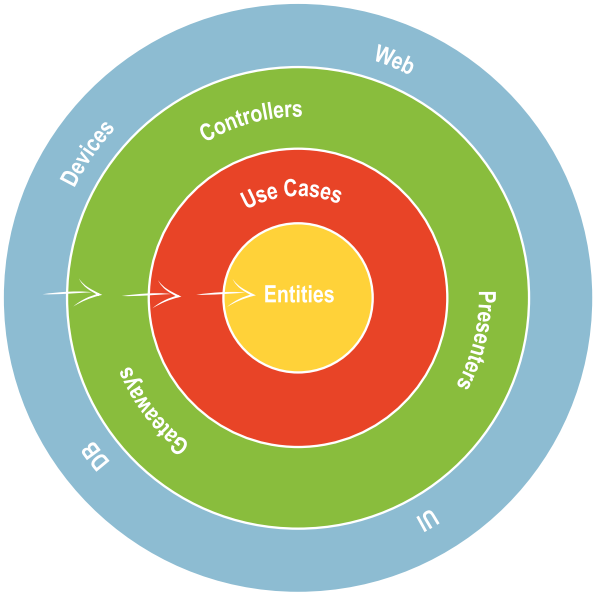
Fighting XSS Attacks (Elm)

```
1.  -- div : List (Attribute msg) -> List (Html msg) -> Html msg
2.  -- text : String -> Html msg

3.  userNameComponent : String -> Html msg
4.  userNameComponent userName =
5.      div [ class "user-name" ] [ text username ]

6.  -- <div class="user-name">Foo</div>
```

Want to Learn About Trusted Types?

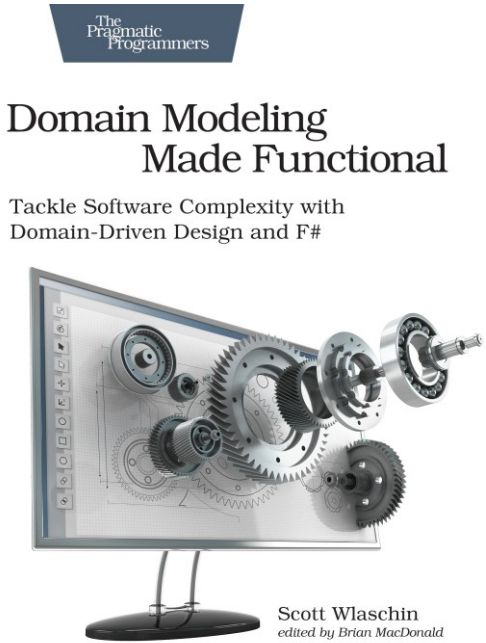
https://www.youtube.com/watch?v=ndk5vFudkMo

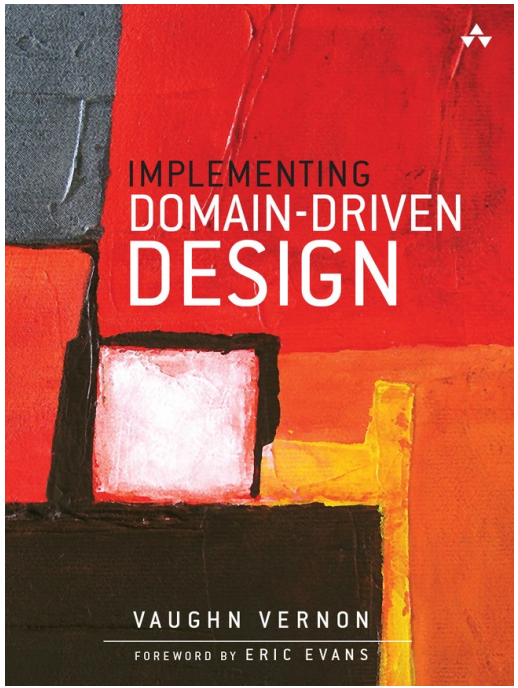
Hexagonal / Onion / Clean Architecture



Source: https://www.4soft.de/blog/2019/clean-architecture/

Book Recommendations





Key Takeaways

- **Make illegal state unrepresentable**
- Encode business rules in your types
- Parse, don’t validate
- Use the compiler to your advantage
- Eliminate security vulnerabilities by design

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