
SBA
Research

Typed Security

Preventing vulnerabilities by design

We Are Developers Security Day – 2024-05-08

Bundesministerium
Klimaschutz, Umwelt,
Energie, Mobilität,
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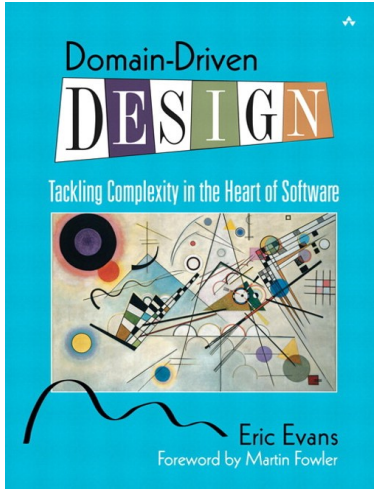
netidee
OPEN INNOVATIONS

$ whoami

- Michael Koppmann
- Security Consultant at SBA Research
  - Web application security
  - Spear phishing simulations
  - Source code audits
  - Architecture reviews
  - Security training
- Software developer

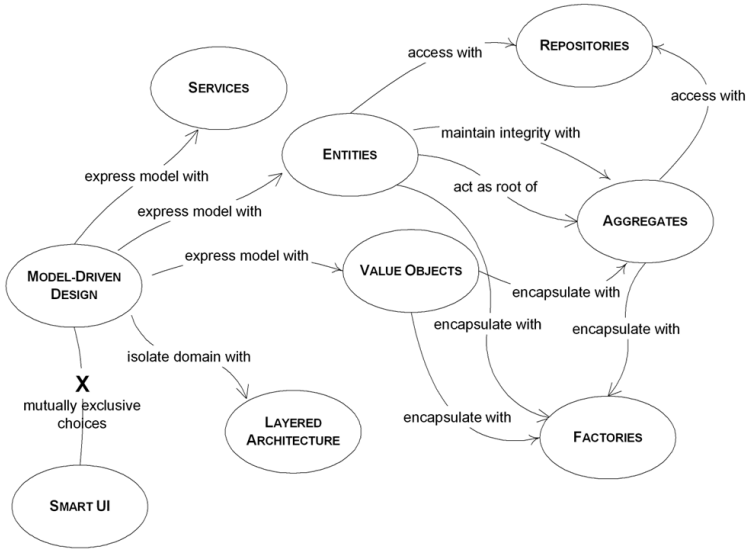
Domain-Driven Design (DDD)



- 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 DDD Concepts

- Entity
- Value object
- Aggregate
- Bounded Contexts
- Repository



Source: Domain-Driven Design – Eric Evans

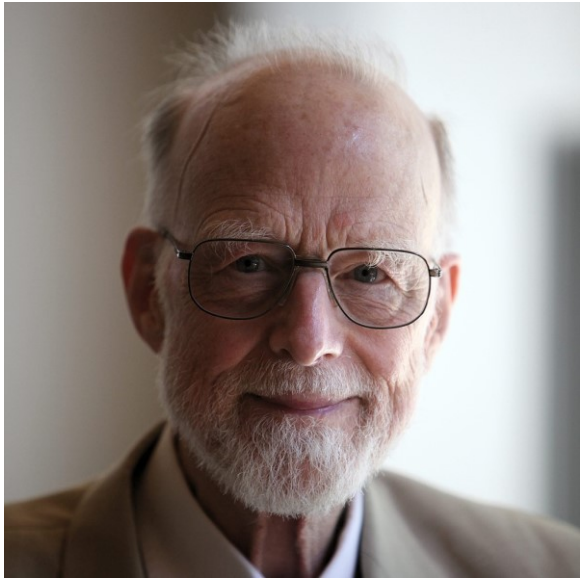
Type-Driven Domain Design

- 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



"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)

```
1.  Optional<String> lookup(String key, Map<String, String> map) {
2.    String value = map.get(key);
3.    return Optional.ofNullable(value);
4.  }

5.  String getContactDescriptionOrDefault(String name,
6.                                        Map<String, String> phonebook) {
7.    Optional<String> opt = lookup(name, phonebook);
8.    return opt.map(number -> name + "'s number is: " + number)
9.              .orElse("Could not find a number for " + name);
10. }
```

The Problem With Basic Data Types

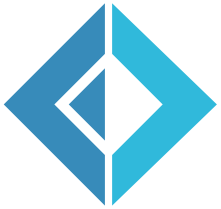
- Relying on them too much is an anti-pattern called “Primitive Obsession”
- No enforcement of constraints
- Any manipulation could invalidate the invariants of the data

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



contact.fs

```
1.  type Contact =
2.      {
3.          FirstName: string;
4.          Initial: string;
5.          LastName: string;

6.          EmailAddress: string;
7.          // true if verification mail was confirmed
8.          IsEmailVerified: bool;
9.      }
```

contact.fs

```
1.  type PersonalName =
2.      {
3.          FirstName: string;
4.          Initial: string;
5.          LastName: string;
6.      }

7.  type EmailContactInfo =
8.      {
9.          EmailAddress: string;
10.         IsEmailVerified: bool;
11.     }

12. type Contact =
13.     {
14.         Name: PersonalName;
15.         EmailContactInfo: EmailContactInfo;
16.     }
```

email.fs

```
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
```

contact.fs

```
1.  type PersonalName =
2.      {
3.          FirstName: String50;
4.          Initial: String1 option;
5.          LastName: String50;
6.      }

7.  type EmailContactInfo =
8.      {
9.          EmailAddress: EmailAddress;
10.         IsEmailVerified: bool;
11.     }

12. type Contact =
13.     {
14.         Name: PersonalName;
15.         EmailContactInfo: EmailContactInfo;
16.     }
```

email.fs

```
1.  type EmailContactInfo =
2.      | Unverified of EmailAddress
3.      | Verified of VerifiedEmailAddress

4.  let EmailAddress = EmailAddress of string
5.  let VerifiedEmailAddress = private VerifiedEmailAddress of string

6.  module EmailVerification =

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

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

18.     let value (VerifiedEmailAddress address) = address
```

contact.fs

```
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
```

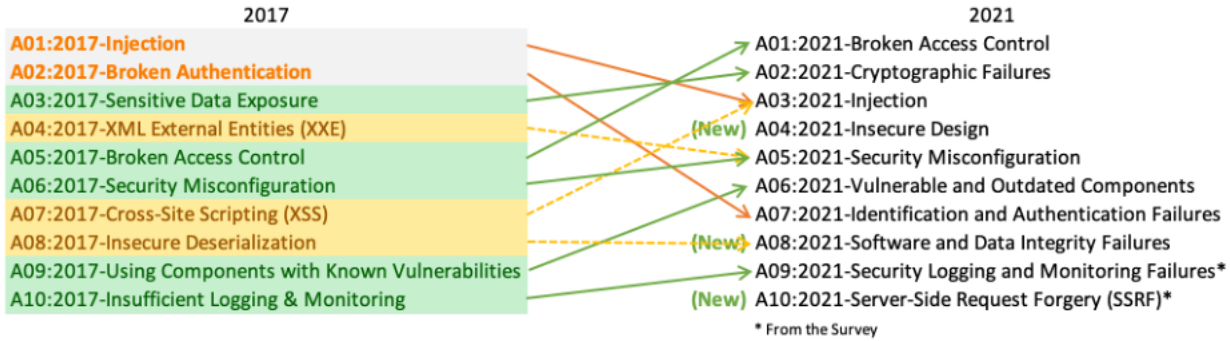
Tackling the OWASP Top Ten

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 (2023)

- API1:2023 Broken Object Level Authorization
- API3:2023 Broken Object Property Level Authorization
- API5:2023 Broken Function Level Authorization

Types For Authorization

Fighting broken access control attacks

articleController.hs

```
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
```

authorization.hs

4.

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

articleService.hs

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

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

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

articleController.hs

```
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)

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

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

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

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

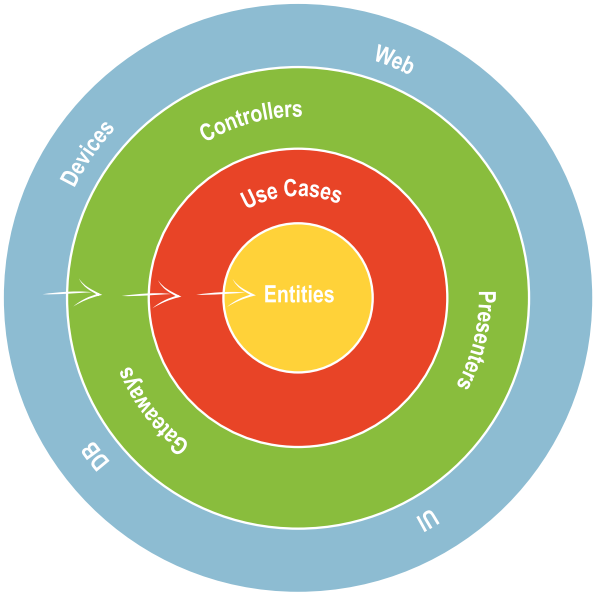
Fighting Object Property Level Authorization (Java)

```
1.  public class User {
2.      private final Id<User> id;
3.      private Name50 firstName, lastName;
4.      private Birthdate dateOfBirth;
5.      private PasswordHash passwordHash;
6.      // Constructor, getters, setters, domain logic, etc.
7.  }
8.  public class UserViewModel {
9.      private final String fullName;
10.     private final DateTime dateOfBirth;
11.     // Constructor, getters, mapping from entity to dto and vice versa
12. }
13. public List<UserViewModel> getUsers(…) {
14.     List<User> users = userService.getUsers(…);
15.     return users.stream().map(UserViewModel::entityToViewModel).collect(Collectors.toList());
16. }
```

Fighting XSS Attacks (Elm)

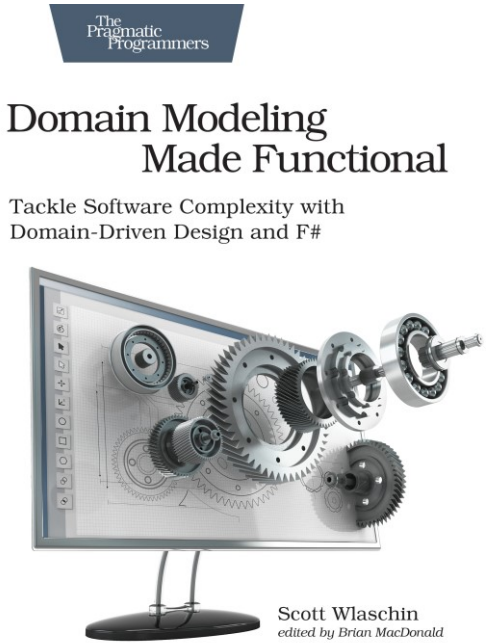
```
1.  -- div : List (Attribute msg) -> List (Html msg) -> Html msg
2.  -- text : String -> Html msg

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

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

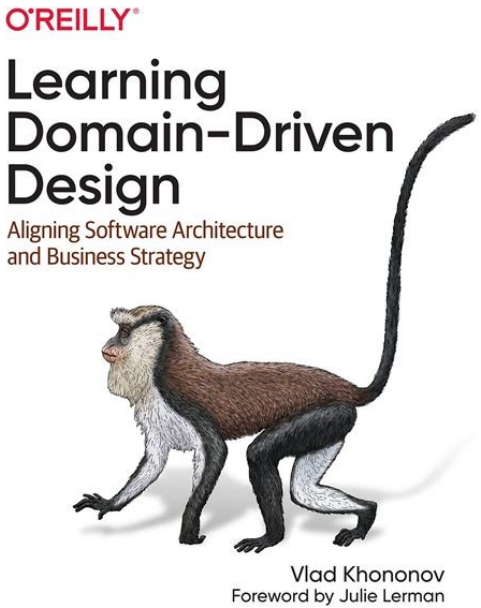
Hexagonal / Onion / Clean Architecture



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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