# SafeWeb

## A Middleware for Securing Ruby-Based Web Applications

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# Data **confidentiality** in **enterprise** web applications

## Focus on applications processing sensitive data

Requirements regarding compliance with legal policies

## Problem of controlling all data flows

Data protection across multiple layers at different granularities

## Common threat model:

1. External environment is **hostile**
2. Application code is **not** explicitly **malicious**
3. Threats might be caused by **bugs** in implementation

# Real-world case study

## Provide web **portal** for accessing patient records

Make patient records accessible for review and feedback purposes

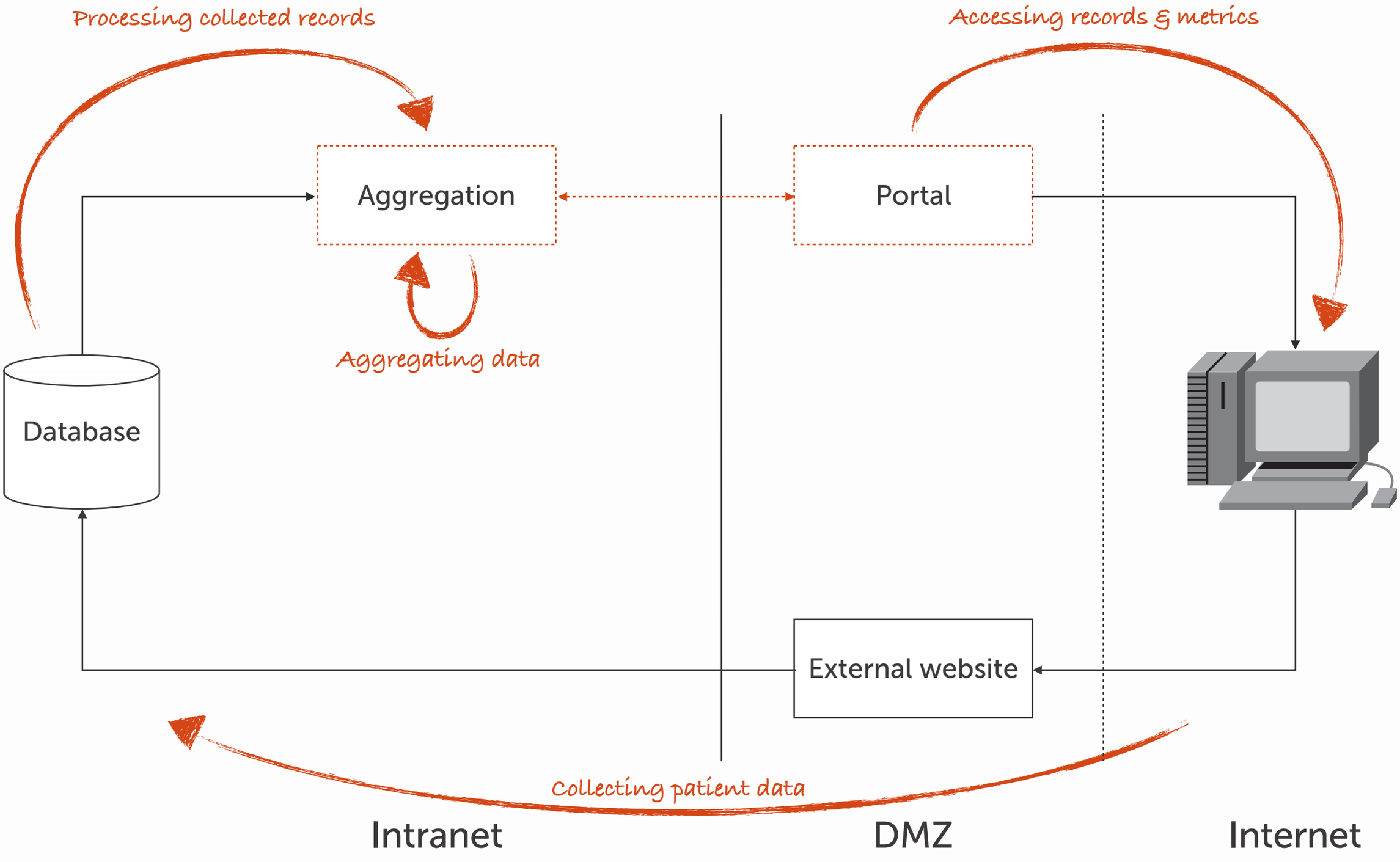
## Strict security policy requirements:

1. Statistics & metric accessible to **all** staff
2. Patient details accessible **only** to patient treating staff

## Current best practices are insufficient

Expensive and error-prone **source code auditing**

Limited exposure of collected data




1. Confidential data should be **protected end-to-end**
2. Access to confidential data by external users should be **static** & **one-way**

# Contributions

## SafeWeb middleware for **end-to-end** data protection

- Uses information flow control for data tracking
- Guarantees data confidentiality and integrity

## Mechanisms for data tracking at different granularities

- Enforcement of data protection at event and variable levels
- Efficient implementation using Ruby dynamic programming features

## Real-world evaluation in a healthcare environment

- Developed & deployed in collaboration with UK National Health Service (NHS)

# OUTLINE

motivation **& contribution**

information flow **control**

SafeWeb **architecture**

label **propagation**

real-world **case study**

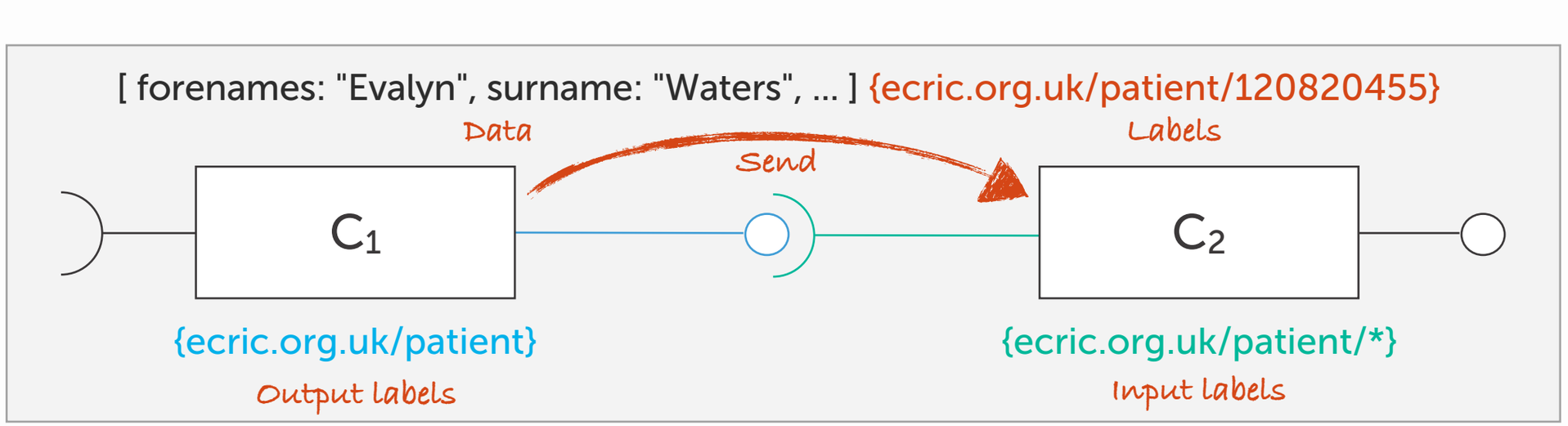
**evaluation**

**conclusions**

# Information flow control

## Protects the propagation of data

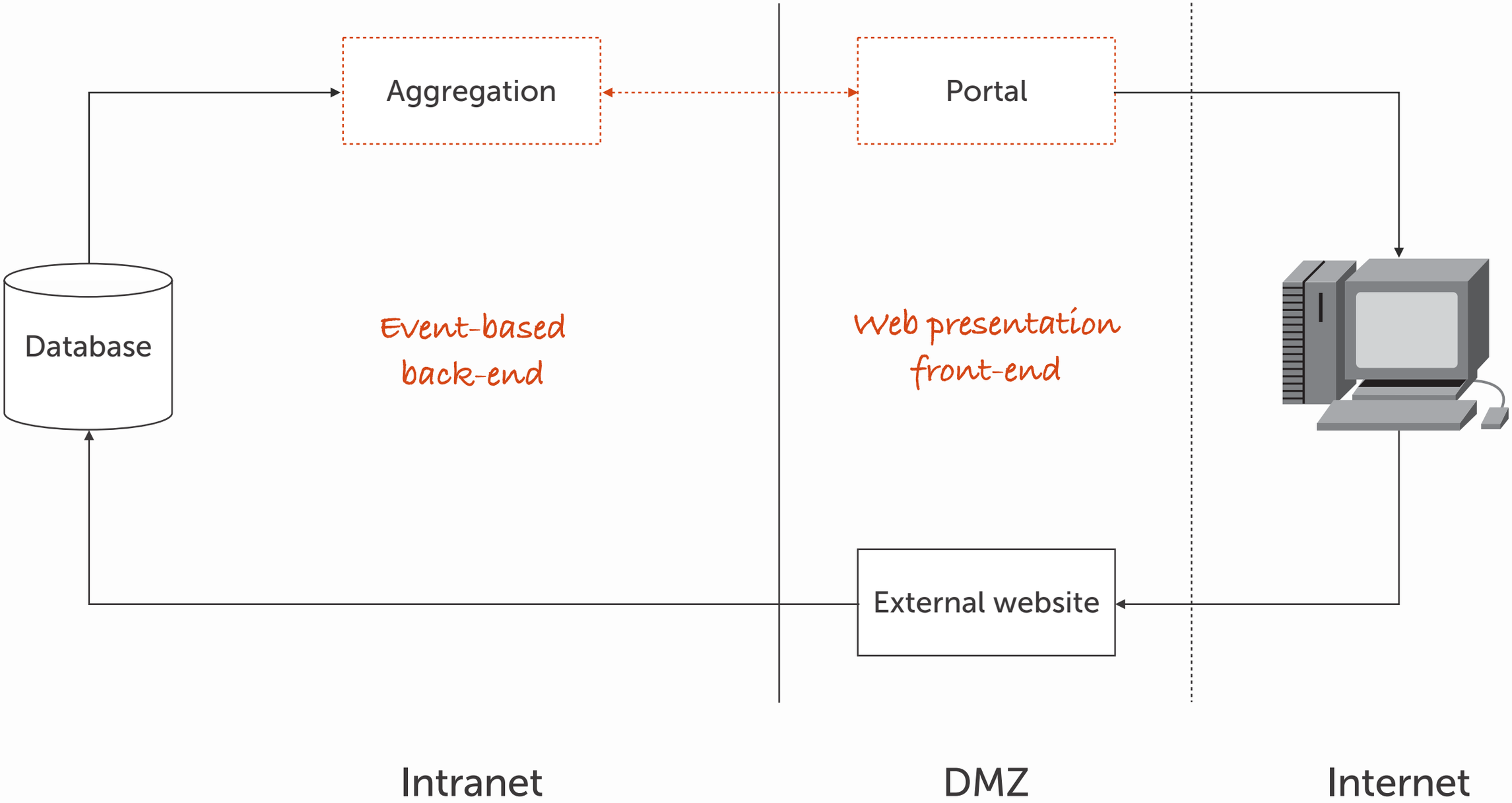
Attaching security labels to data and tracking their propagation




$C_1$ can output event iff {ecric.org.uk/patient} ⊆ {ecric.org.uk/patient/120820455}

$C_2$ can input event iff {ecric.org.uk/patient/120820455} ⊆ {ecric.org.uk/patient/*}

Bell, D., LaPadula, L.: Secure computer system: Unified exposition and Multics interpretation (1976)

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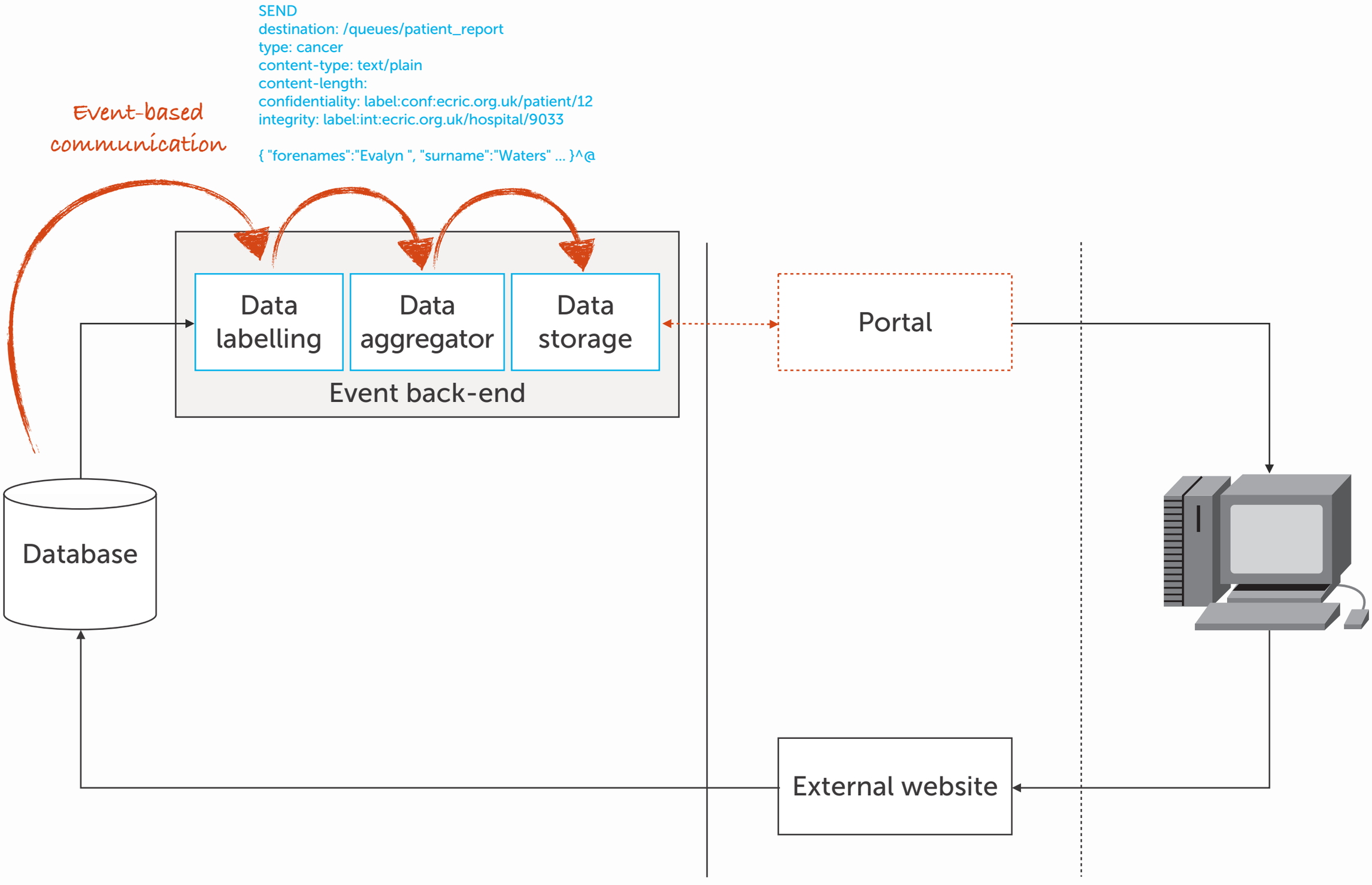


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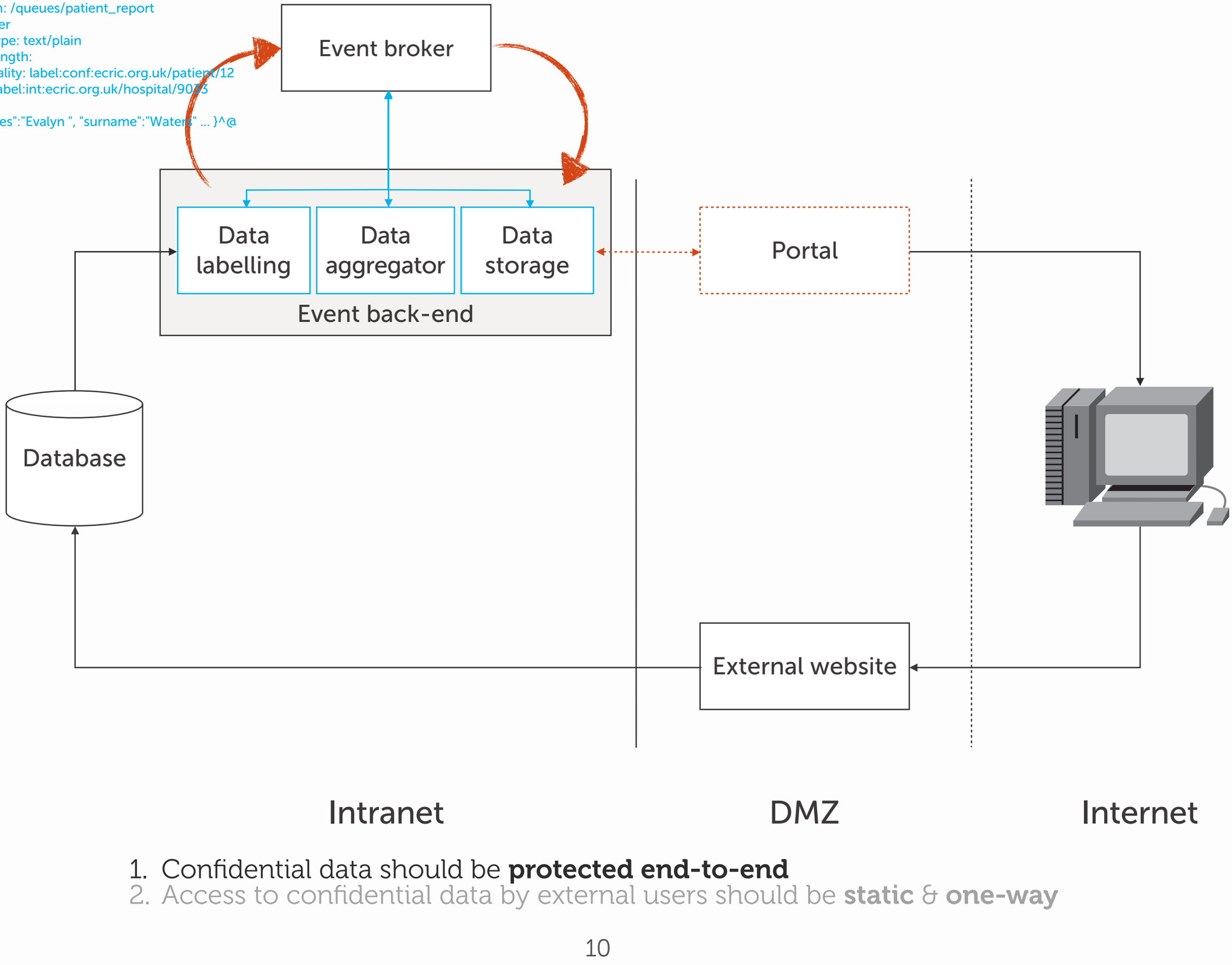
## Event dispatch & filtering

```
SEND
destination: /queues/patient_report
type: cancer
content-type: text/plain
content-length:
confidentiality: label:conf:ecric.org.uk/patient/12
integrity: label:int:ecric.org.uk/hospital/9033

{ "forenames":"Evalyn ", "surname":"Waters" ... }^@
```

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# Event back-end

## Support & control of unit execution

- Checking and tracking events security labels
- Prevent units from **disclosing** confidential data

## Tracking the security labels at the level of **events**

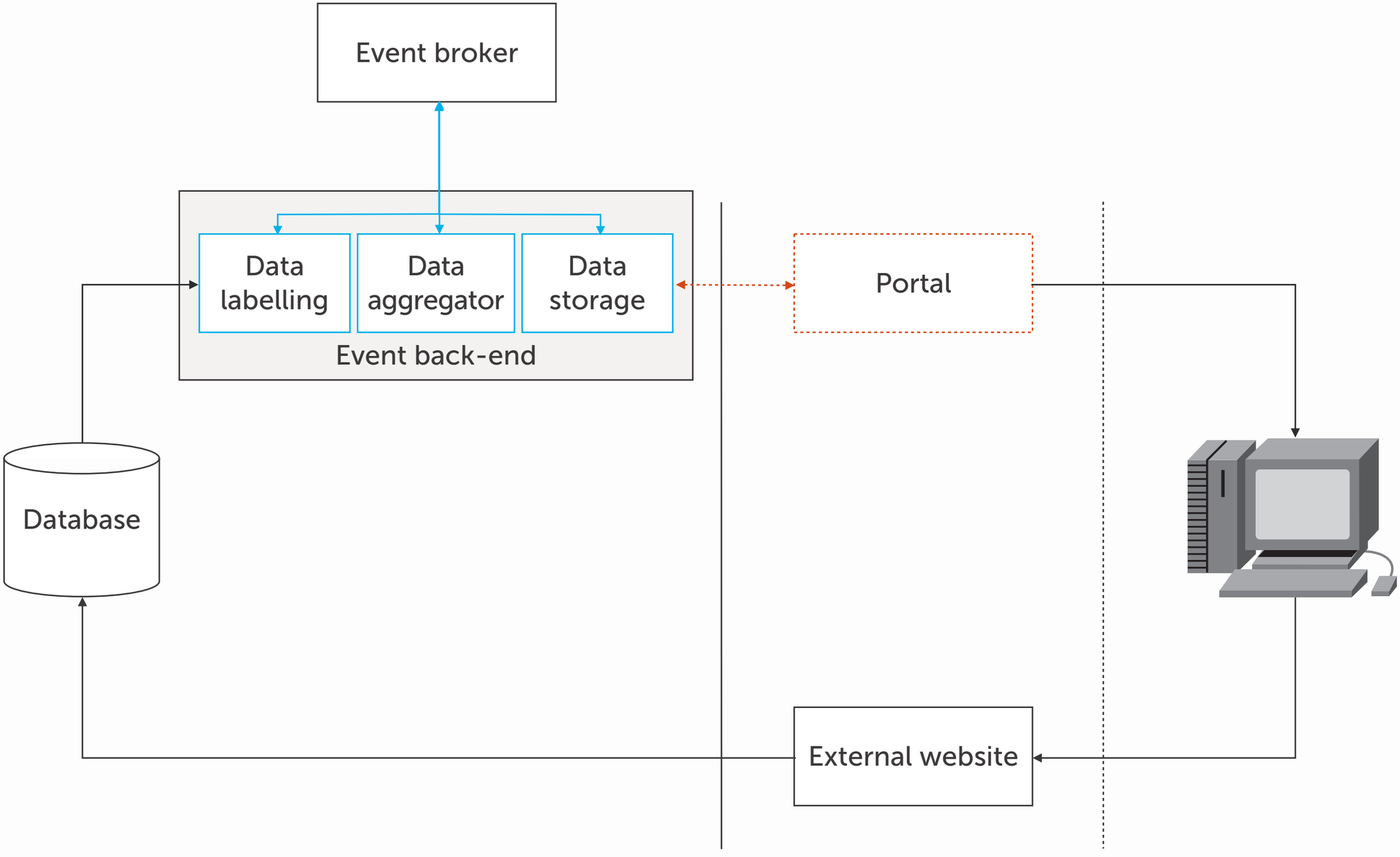
- Simple event data model using set of key-value attribute pairs and data payload
- STOMP-based event protocol extended with support for security labels

## Enforces unit sandboxing & isolation

- Controlling the use of all I/O operations
- Preventing access to variables outside of local scope

```
list = get 'patient_list' << event.patient
puts $patients << event.patient
publish '/daily_report', list, :add => ['label:conf:ecric.org.uk/patient_list']
```

Accessing global variable & I/O operation

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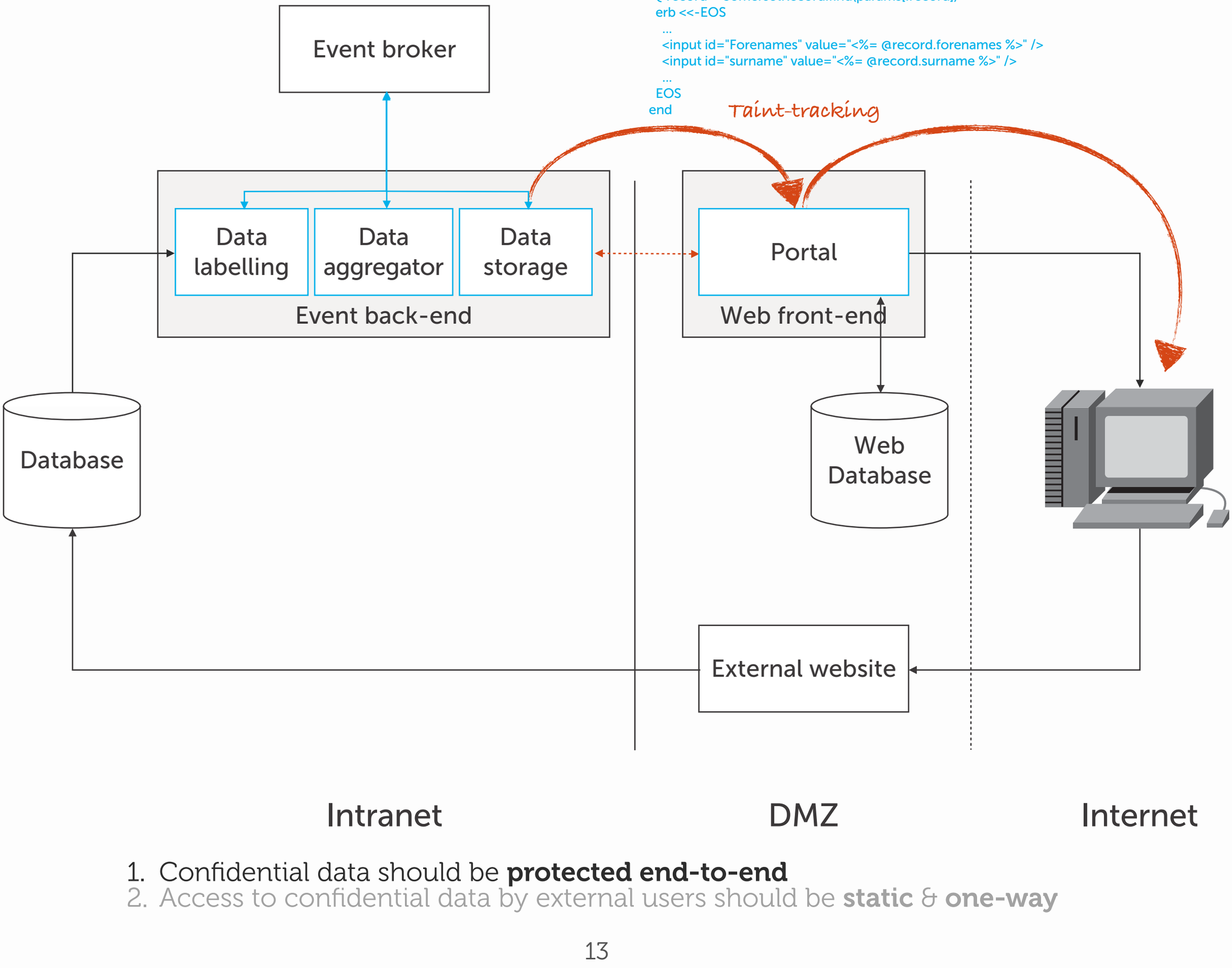
```
get '/record/:record' do
 @record = SomersetRecord.find(params[:record])
 erb <<-EOS
  ...
  <input id="Forenames" value="<%= @record.forenames %>" />
  <input id="surname" value="<%= @record.surname %>" />
  ...
 EOS
end
```

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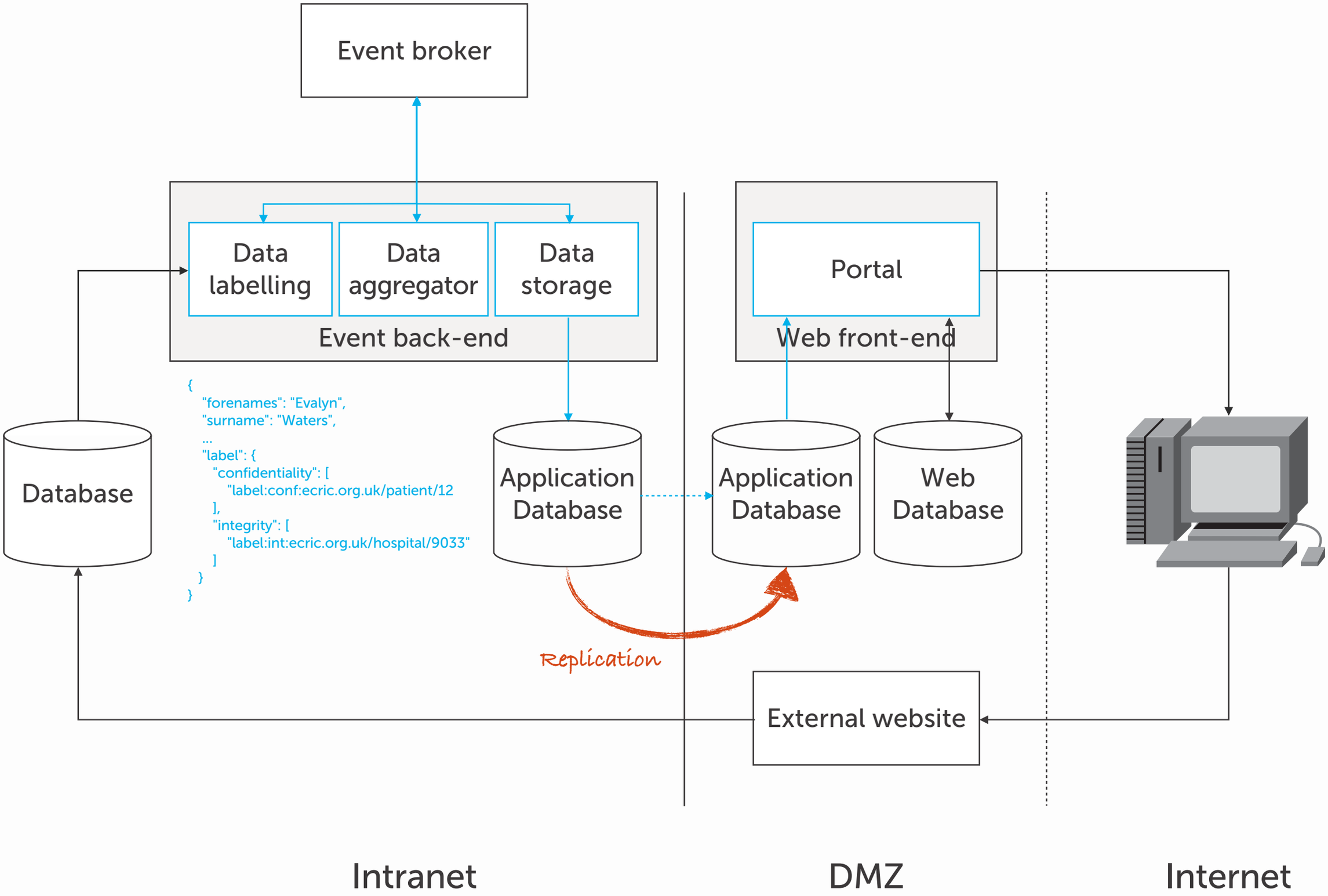


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# Web front-end

## Presents results from back-end to users

- Sinatra-based web framework with traditional database-driven architecture

## Enforces data flow control

- Using data security labels assigned by data processing units

## Taint tracking at the level of **variables**

- Associating security labels with individual variables
- Checking labels on HTTP response

```
@name = @patient.forenames + " " + @patient.surname
@name.add_tags! ['label:ecric.org.uk/patient/fullname']
erb "<input id='name' value='<%= @name >' />"
```

Taint propagation

# Label **propagation**

## **without** runtime or code **modification**

SafeWeb uses **unmodified** Ruby runtime

- Avoiding unnecessary code transformations
- Simplified deployment & maintenance

Sandboxing & isolation through Ruby **$SAFE** levels

- Simple taint-tracking mechanism with set of **predefined** levels

Exploiting Ruby's meta-programming features

- Using Rubinius **meta-circular** Ruby VM implementation

A. Yip et al. Improving Application Security with Data Flow Assertions
S. Naira et al. A Virtual Machine Based Information Flow Control System for Policy Enforcement

```
id = measurement[:id]
report = Report.new(measurement)

subscribe "/queues/measurements/#{id}/cancer_cases" do |event|
   report.append event
end

subscribe '/queues/measurements/release' do |timestamp|
   report.mark timestamp
   publish '/queues/reports', report
end
```

**Snippet of patient record aggregation logic**

Part of data aggregator unit

```
id = measurement[:id]
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```
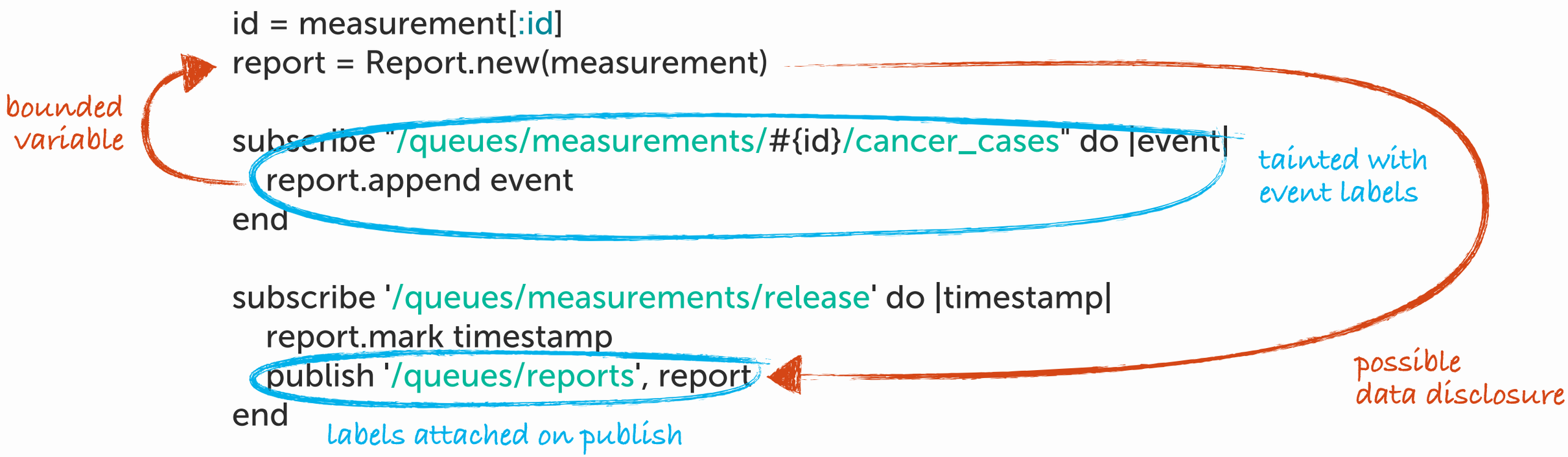

tainted with event labels

labels attached on publish

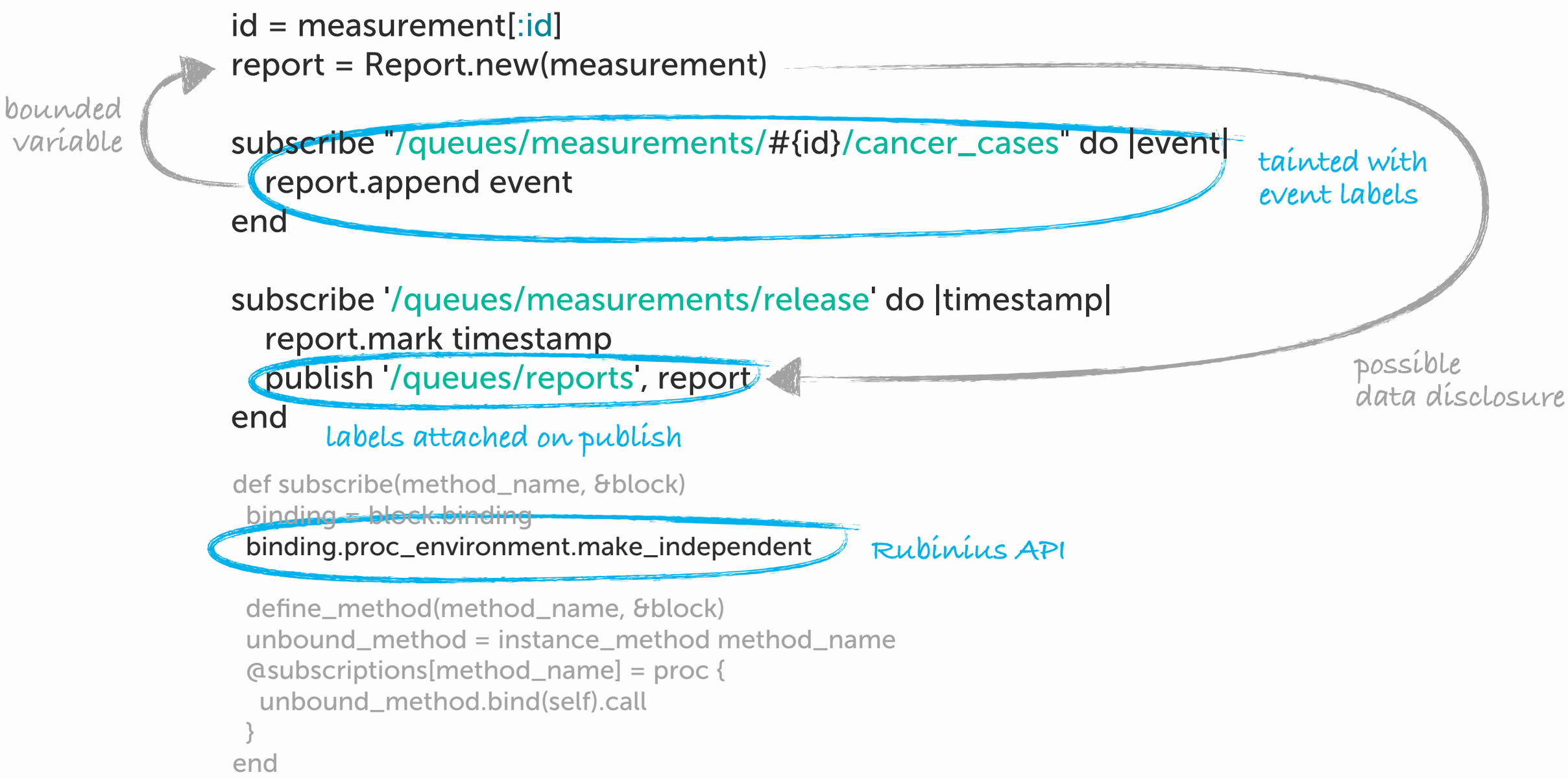
**Snippet of patient record aggregation logic**

Part of data aggregator unit




**Snippet of patient record aggregation logic**

Part of data aggregator unit




**Snippet of patient record aggregation logic**

Part of data aggregator unit

```
id = measurement[:id]
report = Report.new(measurement)
set id, report

subscribe "/queues/measurements/#{id}/cancer_cases" do |event|
  report = get id
  report.append event
  set id, report
end

subscribe '/queues/measurements/release' do |timestamp|
  report = get id
  report.mark timestamp
  publish '/queues/reports', report
end
```

tainted with event labels

tainted with stored data labels

labels attached on publish

**Snippet of patient record aggregation logic**

Part of data aggregator unit

# **Real-world** case study
## in a healthcare organisation

## Eastern Cancer Registry and Information Centre (ECRiC)

Collects histories of cancer cases in the East of England

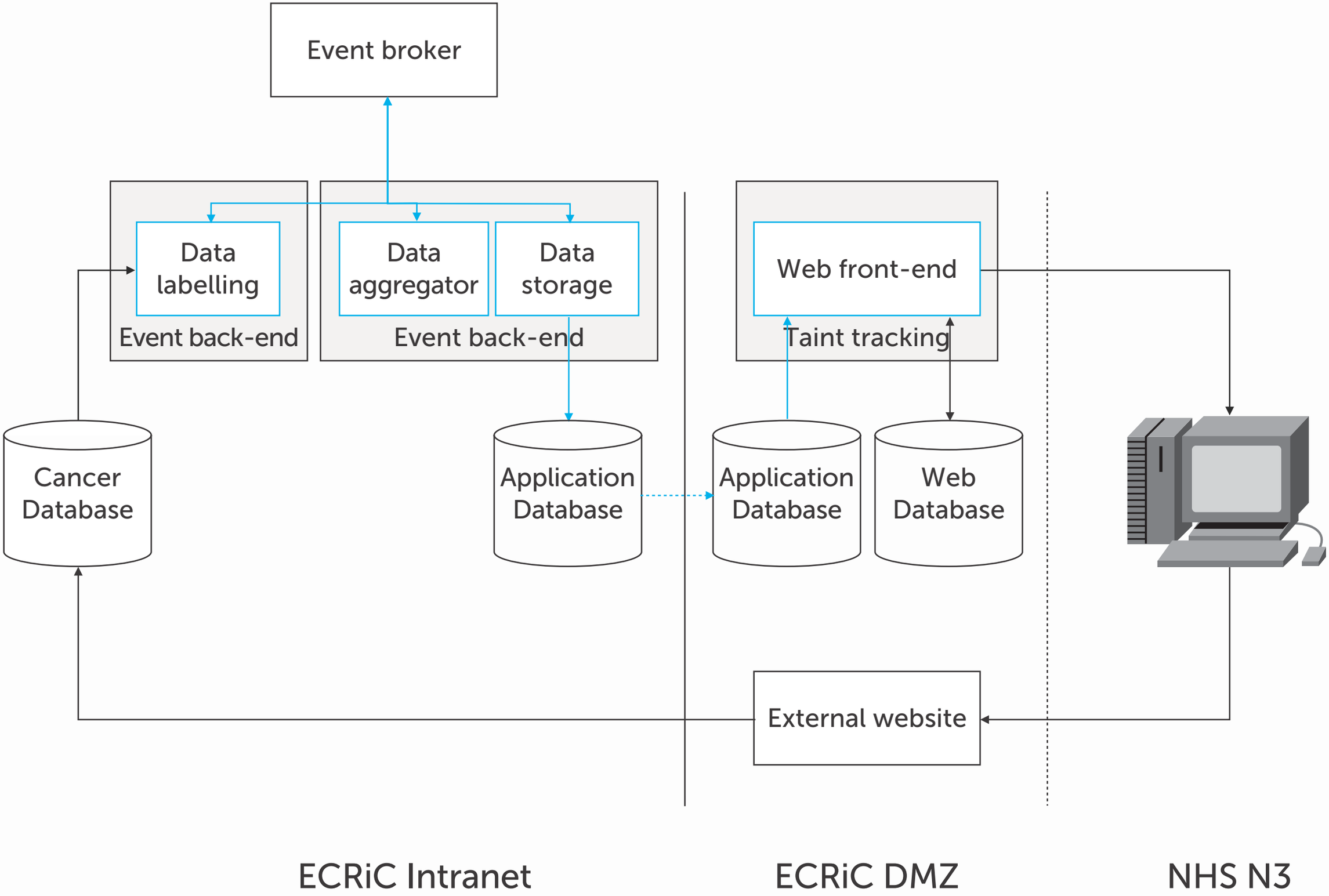
## Aims to provide patient records feedback application

Following the existing data protection & security requirements

## Compatibility with existing production environment

No changes at organisational or infrastructure level

Reusing the components of existing system implemented in Ruby




**Real-world deployment**

Within ECRiC

# Multi Disciplinary Team Feedback Portal

admin

Hinchingbrooke Hospital (includes Mulberry Suite)

This applications shows the completeness of certain key data items received each month by a Trust as discussed at Multi Disciplinary Teams. By clicking on your Trust from the map above, all the relevant data will appear on the performance chart to the right. You can see the detailed patient records (you are entitled to see) by clicking on the row to expand this and see the underlying data.

| | Type | Month | Hospital | Total | Date Checked | Data Completeness |
|---|---|---|---|---|---|---|
| – | Breast | 2010-11 | HINCHINGBROOKE HOSPITAL (INCLUDES MI | 23 | 23/02/2011 | |

| NHS Number | Forename | Surname | Address | Postcode | Date of Birth | Diagnosis Date |
|---|---|---|---|---|---|---|
| 143354460 | Tomas | Denesik | 100 Pierce Grove,West Yasmin | LG33 4FI | 26/06/1977 | 27/11/2010 |
| 107811786 | Pietro | Gorczany | 2329 Bogisich Forest,Morissettemouth | RI4 5GN | 03/06/1950 | 14/11/2010 |
| 188365946 | Abagail | Fisher | 59228 Toy Vista,Larkinbury | SK6 2QE | 20/02/1964 | 12/09/2010 |
| 191462777 | Alexa | Stehr | 6277 Micah Place,Williamsonmouth | LG89 0KU | 11/02/1975 | 21/11/2010 |
| 105977731 | Dolly | Grant | 2127 Kolby Lake,Wallacebury | LS69 0BI | [illegible] | 29/11/2010 |
| 134034634 | Marco | Schmeler | 867 April Estates,Lake Coby | PY8 9VH | 21/06/1974 | 29/11/2010 |
| 162926852 | Hosea | Nolan | 54563 Feeney Bypass,North Dortha | BH6 1GR | 13/11/1978 | 02/11/2010 |
| 114622039 | Domingo | Pfeffer | 5795 Terry Creek,New April | FO6 6AO | 20/11/1972 | 01/09/2010 |
| 105728923 | Van | Hill | 95066 Vickie Land,Geoffreyburgh | VP2 4CC | 06/01/1947 | 03/09/2010 |
| 173023494 | Zack | Daugherty | 5047 Kohler Rest,Nicolasside | EE75 0FU | 24/03/1945 | 25/10/2010 |
| 194606875 | Buford | Hermiston | 87732 Donnelly Neck,Lake Albina | YH37 3ZG | 24/08/1977 | 24/10/2010 |
| 194299780 | Jimmie | Ernser | 71845 Albertha Dale,East Delmer | LP72 6PM | 02/01/1965 | 21/10/2010 |
| 150007601 | Savanah | Powlowski | 2011 Demetris Ramp,Durganfurt | ZG80 3JB | 01/02/1976 | 14/09/2010 |
| 186725183 | Shyanne | Kuhic | 66077 Clementina Ranch,Armstrongbury | VB3 3OI | 28/05/1962 | 15/10/2010 |
| 120820455 | Evalyn | Waters | 90326 Jadon Stream,East Dino | BK38 4GX | 10/03/1962 | 26/10/2010 |
| 115405275 | Marlon | Hoppe | 4787 Bennie View,Hudsonbury | UL5 1ZM | 05/06/1963 | 19/11/2010 |
| 115261382 | Khalil | Schamberger | 9467 Kasey Mills,North Johnathon | TW83 0NO | 06/05/1940 | 11/11/2010 |
| 196659038 | Easter | Veum | 92279 Gutmann Hills,Filibertofurt | RH9 8KI | 26/02/1951 | 17/09/2010 |
| 182459356 | Vladimir | Kozey | 591 Fadel Valley,South Corrine | YH18 1OC | 13/09/1961 | 16/10/2010 |
| 192887891 | Lia | Conroy | 35313 Turcotte Mount,Baumbachville | EI97 7GF | 18/11/1973 | 16/10/2010 |

| | | | | | | |
|---|---|---|---|---|---|---|
| + | Gynae | 2010-11 | HINCHINGBROOKE HOSPITAL (INCLUDES MI | 7 | 23/02/2011 | |
| + | Haematology | 2010-11 | HINCHINGBROOKE HOSPITAL (INCLUDES MI | 6 | 23/02/2011 | |
| + | Head & Neck | 2010-11 | HINCHINGBROOKE HOSPITAL (INCLUDES MI | 0 | 23/02/2011 | |

ecric NHS Imperial College London UNIVERSITY OF CAMBRIDGE EPSRC

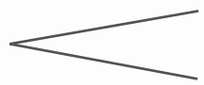
Powered by SmartFlow Event Based Middleware. Built using the SafeWeb Architecture.

# Security improvements

## Prevents common vulnerabilities (from CVE database)

| type of vulnerability | related CVE reports |
|---|---|
| **omitted** access checks | 2011-0701, 2010-2353, 2010-0752 |
| **errors** in access checks | 2011-0449, 2010-3092, 2010-4403 |
| **inappropriate** access checks | 2010-4775, 2009-2431 |
| **design errors** | 2011-0899, 2010-3933 |

## Only a small trusted code-base requires code audit

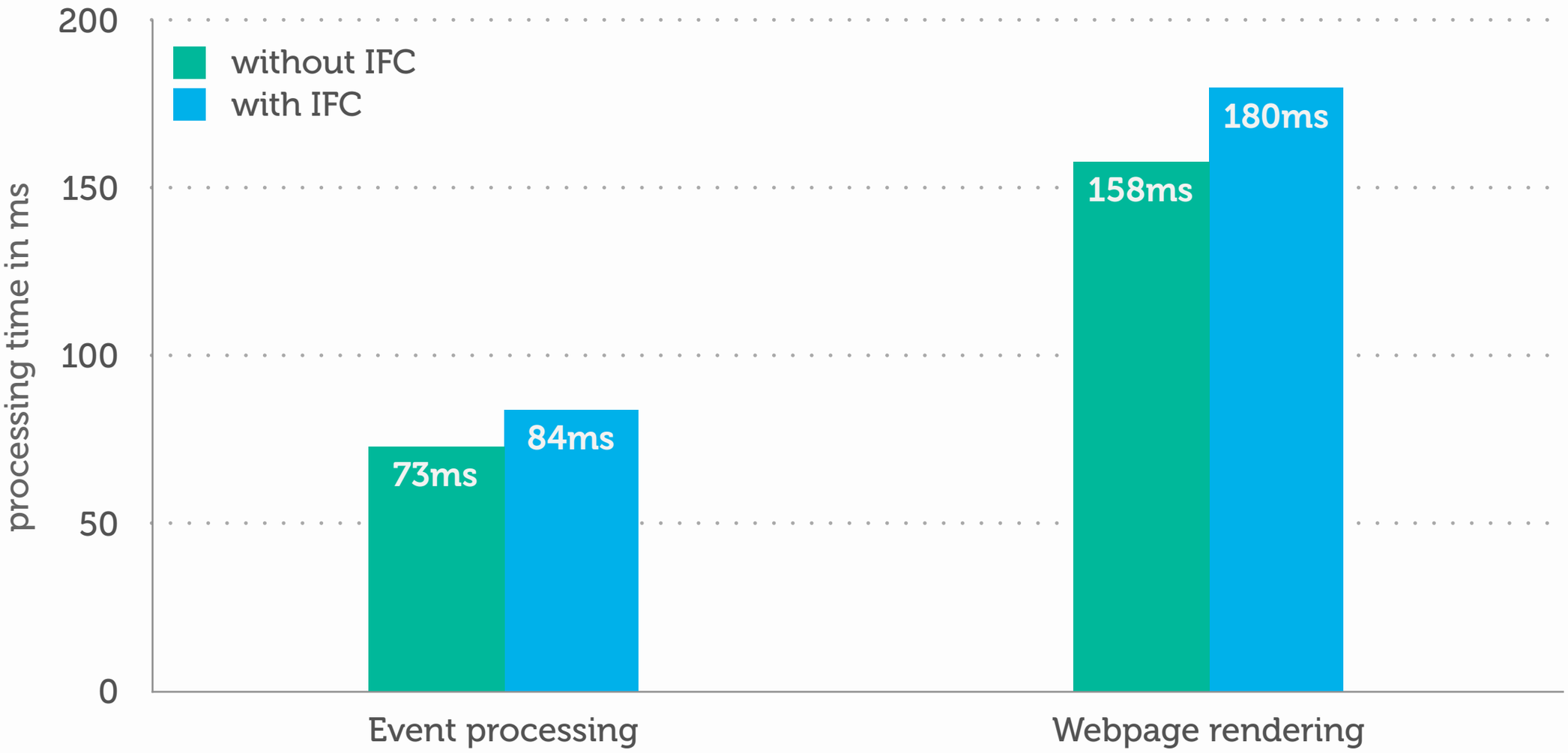
3121 LOC feedback portal 

2841 LOC unprivileged code

280 LOC privileged code

**+14%** event processing latency

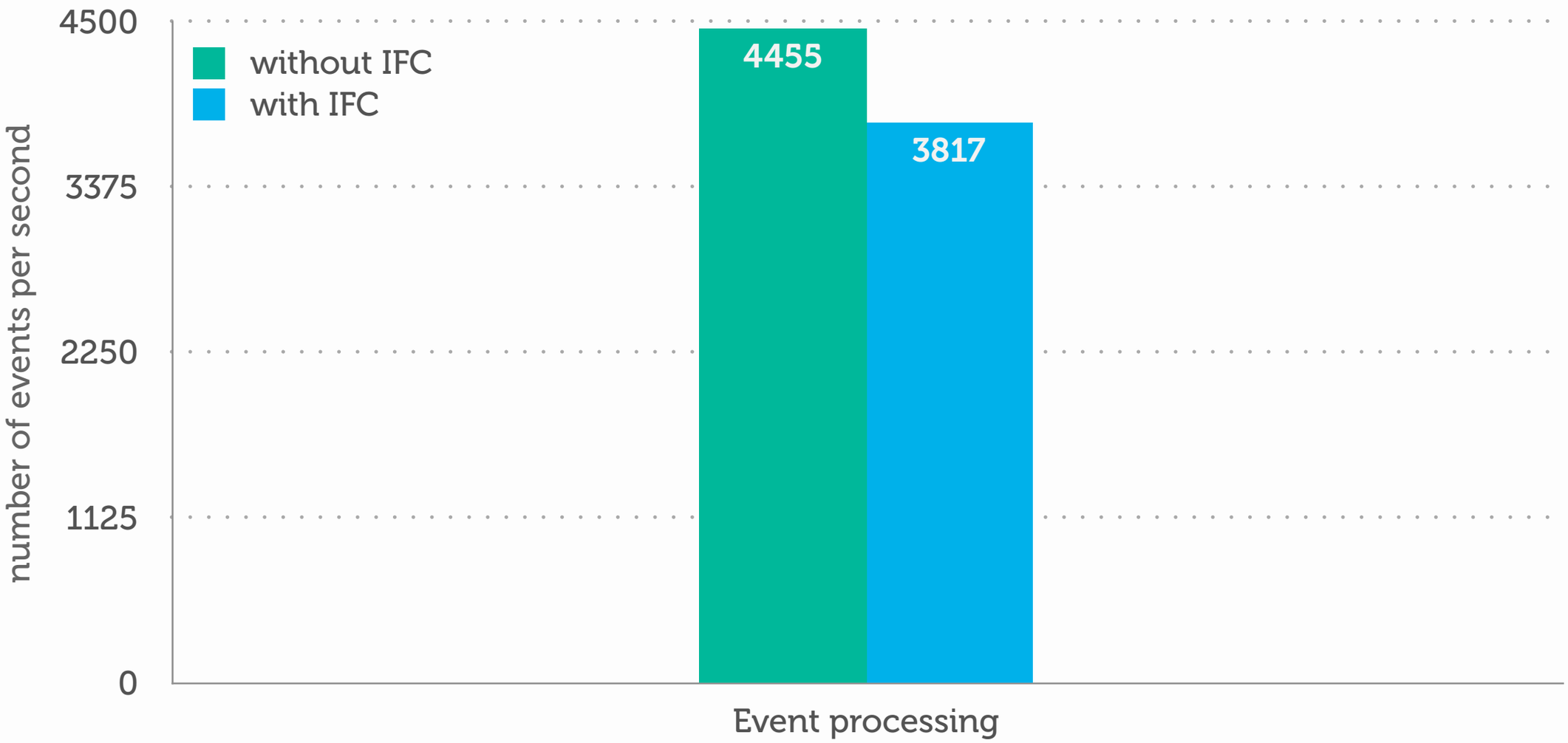
**+15%** webpage rendering latency




**Measured the time to handle/process 1000 requests/events**

Taken on AMD Opteron 6136 2.4GHz, 16GiB of RAM, Ubuntu 10.04

# -17% **event processing** throughput




**Sampled throughput once per second for 1000 seconds**

Taken on AMD Opteron 6136 2.4GHz, 16GiB of RAM, Ubuntu 10.04

# Conclusions

## Control over data flows in enterprise web applications

Data protection across multiple layers at different granularities

## Strong end-to-end security guarantees

Application of information flow control to both back-end & front-end

## The importance of efficient isolation as lesson learned

Necessary to ensure data protection & prevent undisclosed data leaks

## Real-world demonstration in a healthcare environment

Part of a web application for assisting cancer treatment practices within the UK NHS

SafeWeb, part of the EPSRC-funded SmartFlow project
http://smartflow.org/safeweb

# Related work

## Taint tracking for Ruby on Rails web application framework

Burket, J., Mutchler, P., Weaver, M., Zaveri, M., Evans, D.: GuardRails: A data-centric web application security framework (2011)

## Taint tracking using fine grained policy objects and source code rewriting

Yip, A., Wang, X., Zeldovich, N., Kaashoek, M. F.: Improving Application Security with Data Flow Assertions (2009)

## Using Java bytecode rewriting to propagate labels

Yoshihama, S., Yoshizawa, T., Watanabe, Y. Kudoh, M. Oyanagi, K.: Dynamic Information Flow Control Architecture for Web Applications (2007)

## Java thread isolation allowing communication only through labeled data

Migliavacca, M., Papagiannis, I., Eyers, D., Shand, B., Bacon, J., Pietzuch, P.: High-performance event processing with information security (2010)

## JVM runtime modifications to support label tracking

Roy, I., Porter, D., Bond, M., McKinley, K., Witchel, E.: Laminar: Practical fine-grained decentralized information flow control (2009)