SUPOR: Precise and Scalable Sensitive User Input Detection for Android Apps

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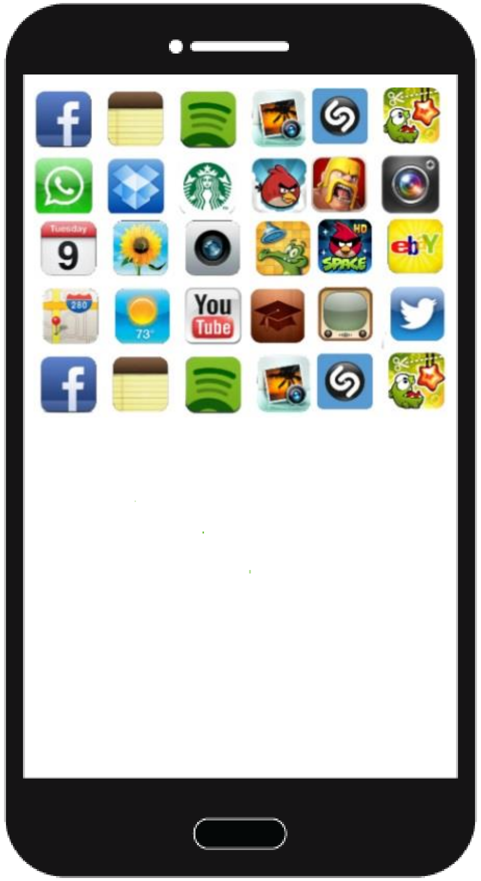
PURDUE UNIVERSITY

NEC Laboratories America
Relentless passion for innovation

Georgia Tech

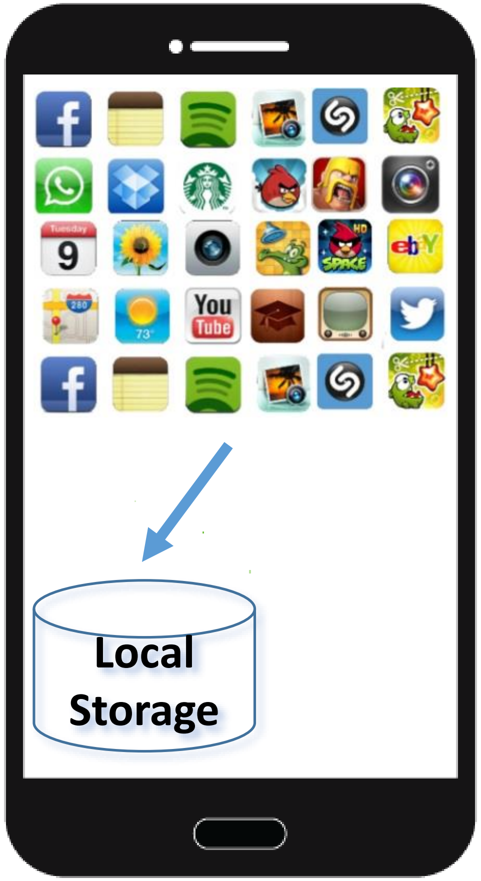
Sensitive Data Disclosures



→ Disclosed to public

→ Hijacked/maliciously retrieved

Sensitive Data Disclosures



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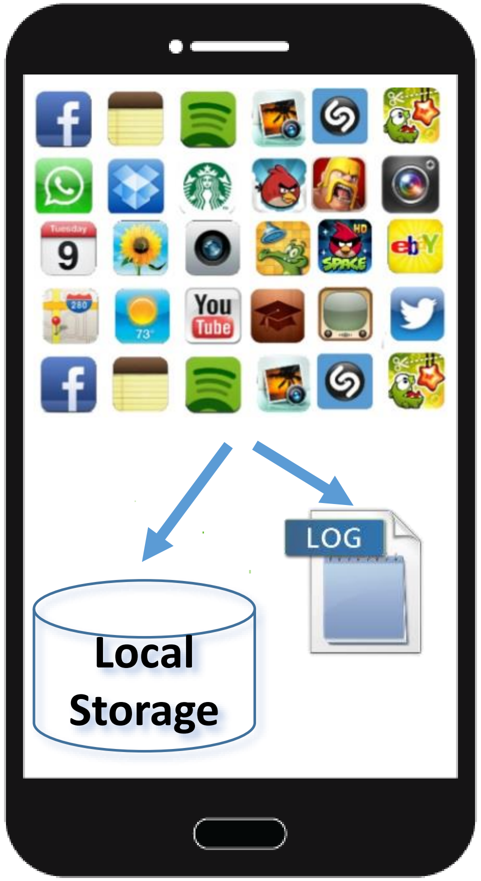

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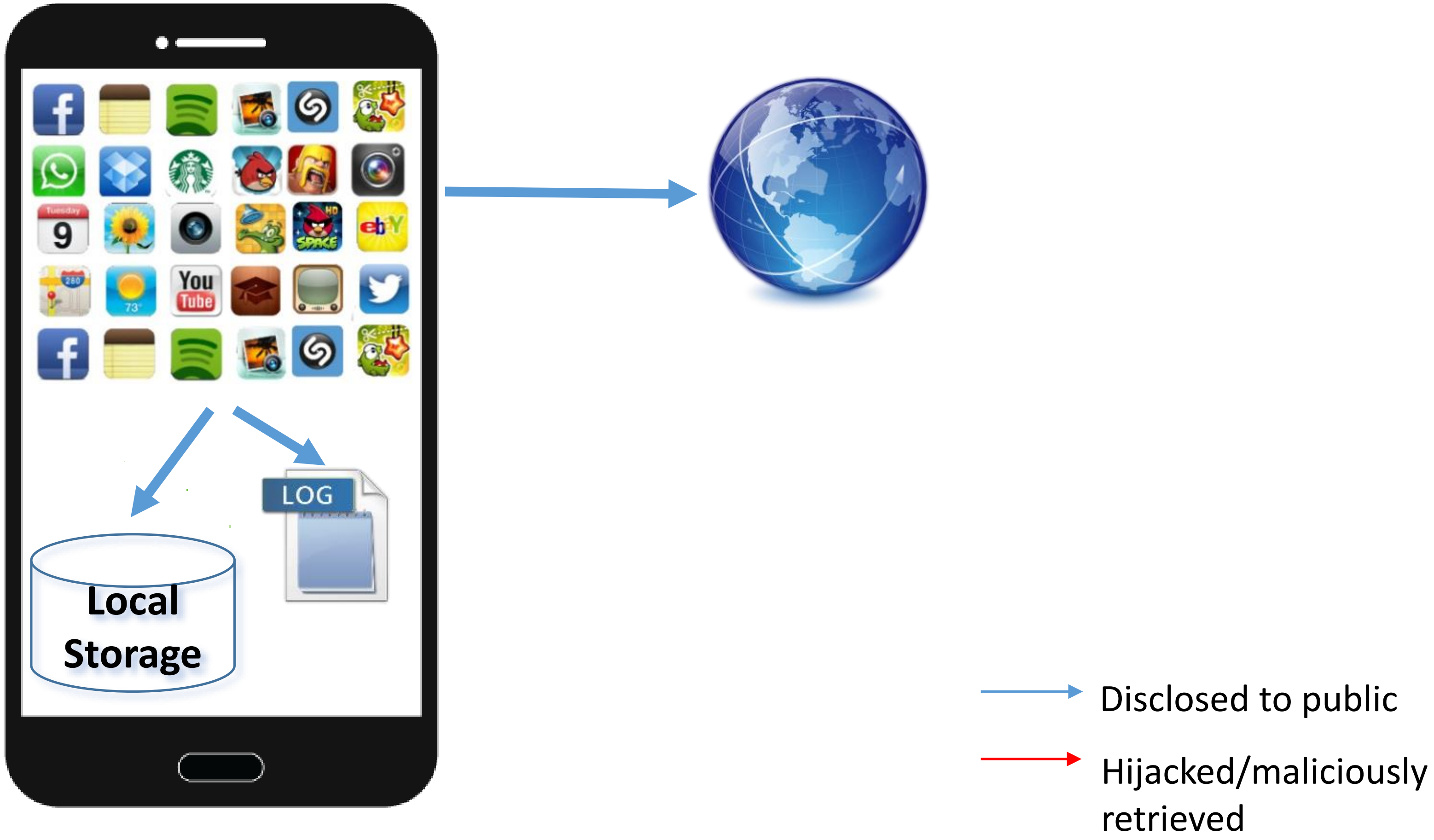

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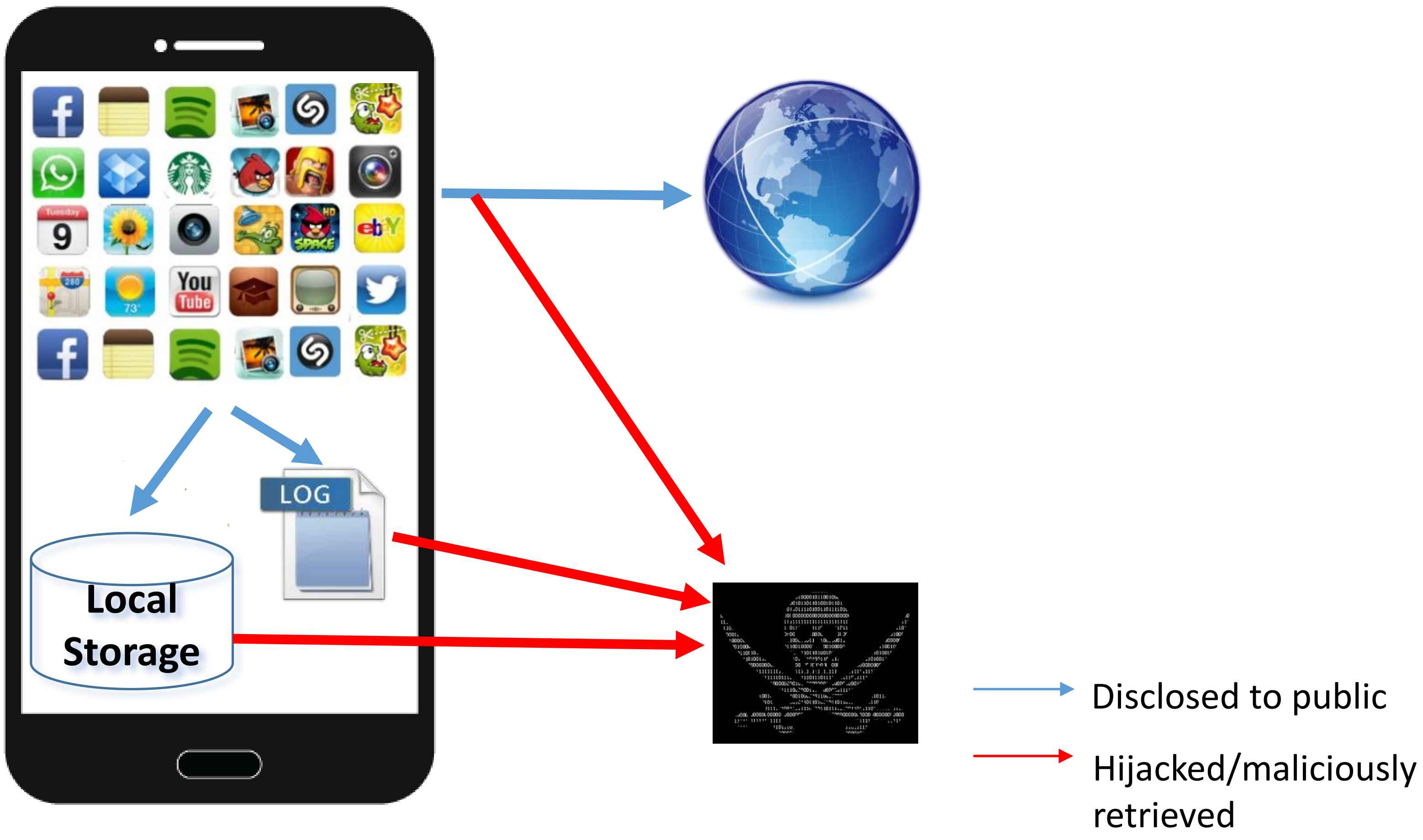

Disclosed to public

Hijacked/maliciously retrieved

Sensitive Data

- Existing work focused on sensitive data defined by certain API methods.

TaintDroid[OSDI’10], AndroidLeaks[TRUST’12], FlowDroid[PLDI’14]

PiOS[NDSS’11]

Sensitive Data

- Existing work focused on sensitive data defined by certain API methods.
  - Most of them are permission protected
  - E.g., in Android, `TelephonyManager.getDeviceId()`

Sensitive User Inputs

- We are among the *first* to detect user inputs as sensitive sources in mobile apps.
  - None of them are permission protected
  - E.g., user id/password, credit card number…

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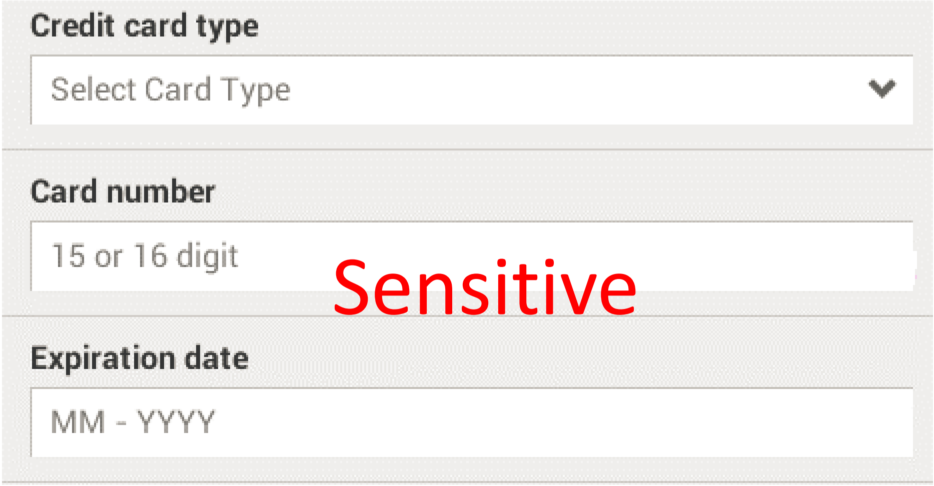

Credit card type

Select Card Type

Card number

15 or 16 digit

Expiration date

MM - YYYY

Sensitive

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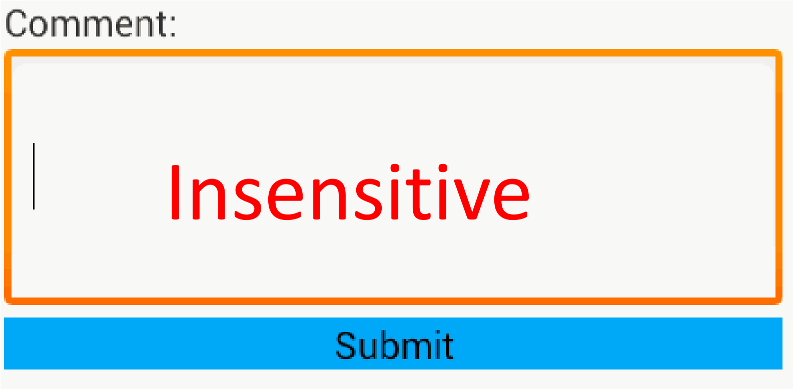
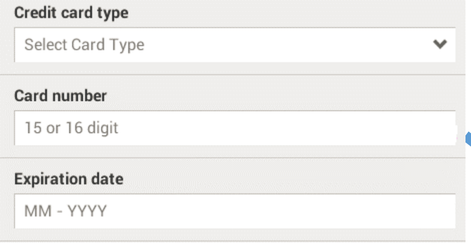


Insensitive

Example User Inputs Disclosures



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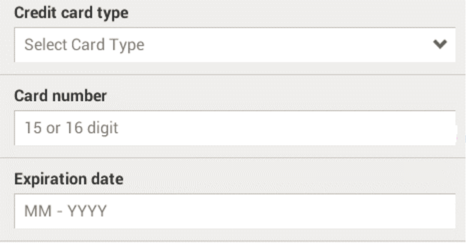
```
EditText txtCN = findViewById(R.id.cardnum);
String cnum = txtCN.getText().toString();
…
```

HTTP

Web Server

Example User Inputs Disclosures



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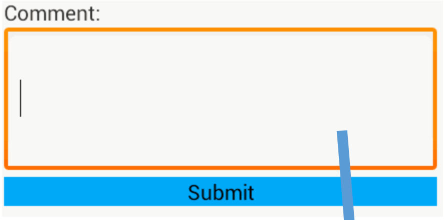

Comment:

```
EditText txtCN = findViewById(R.id.cardnum);
String cnum = txtCN.getText().toString();
…
```

```
EditText txtCM = findViewById(R.id.comment);
String comment = txtCM.getText().toString();
…
```

HTTP

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Web Server

Research Problems

- How to systematically discover the input fields from an app’s UI?
- How to identify which input fields are sensitive?
- How to associate the sensitive input fields to the corresponding variables in the apps that store their values?

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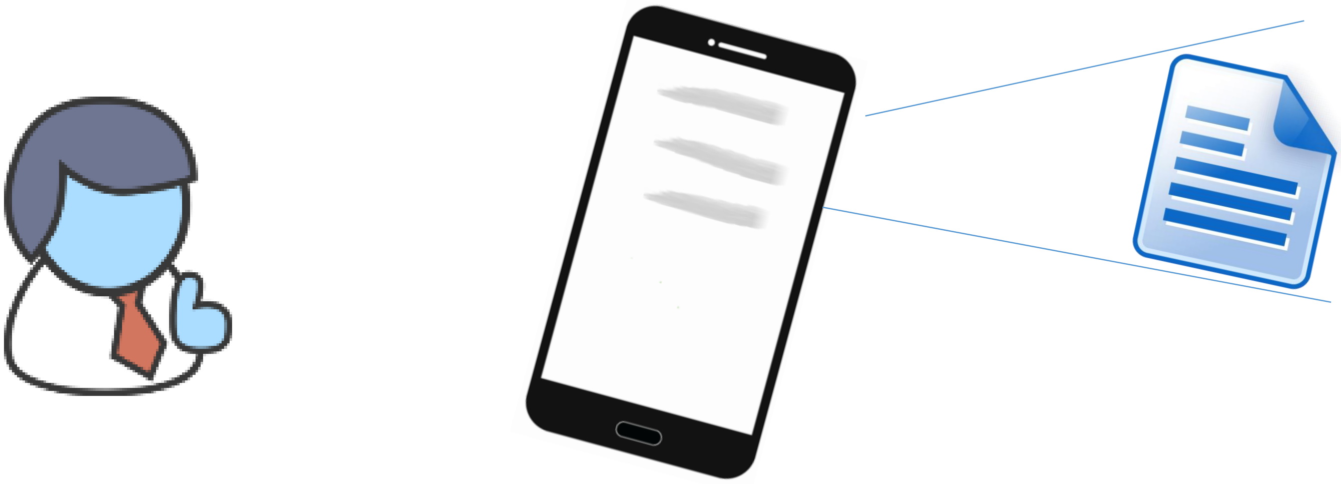
Intuition

- From the **user's perspective**, if we can mimic how a user looks at the UIs, we can determine which input fields can contain sensitive data within the UI context.



Feasibility

- Render the statically defined UI layouts

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	Android	iOS	Windows Phone
Layout format	XML	NIB/XIB/Storyboard	XAML/HTML
Static UI Render	ADT	Xcode	Visual Studio
APIs map widgets to code	Yes	Yes	Yes

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	Android	iOS	Windows Phone
Layout format	XML	NIB/XIB/Storyboard	XAML/HTML
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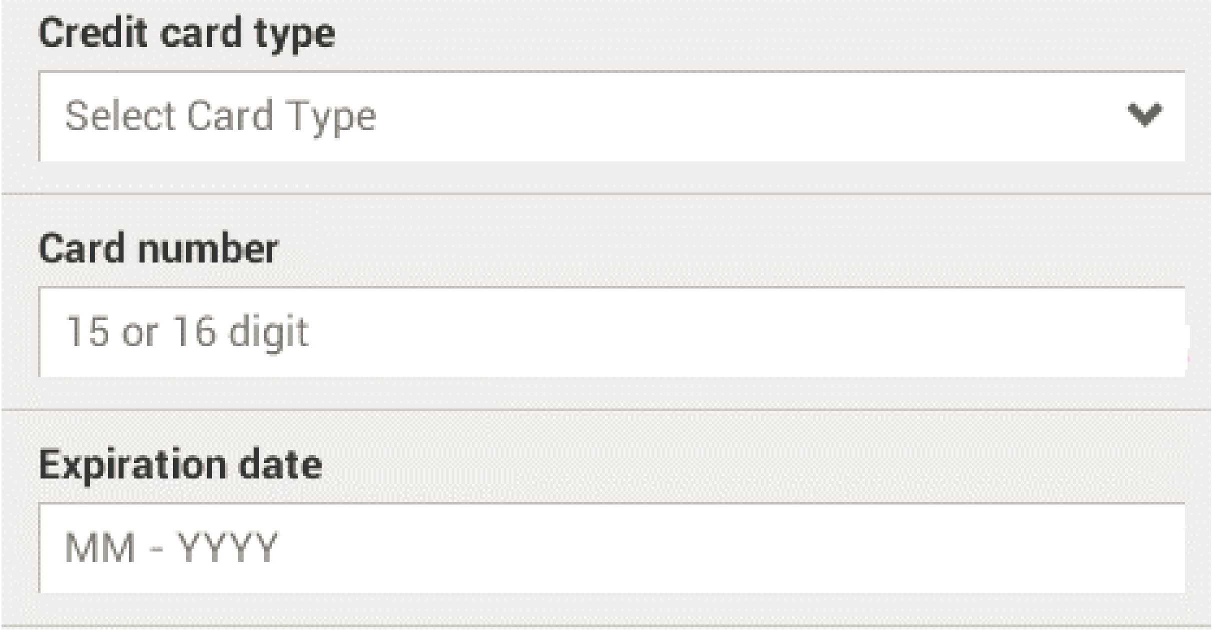
APIs map widgets to code	Yes	Yes	Yes

- Associate labels to input fields based on physical locations

SUPOR:
Sensitive User inPut detectOR

Background - UI



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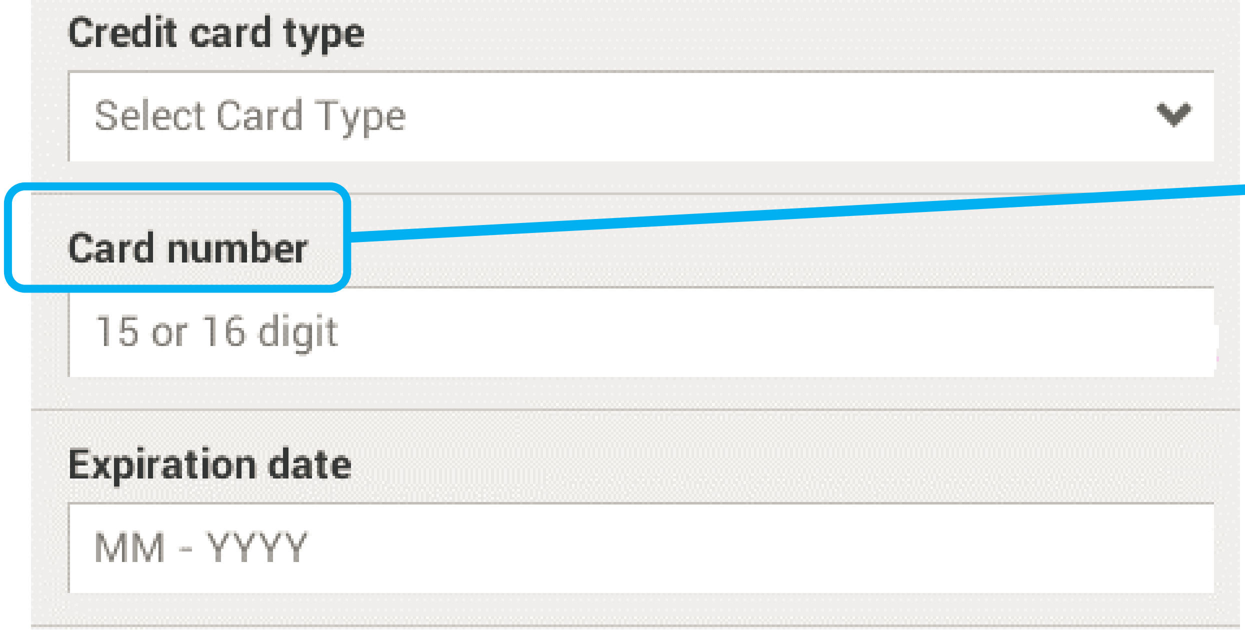

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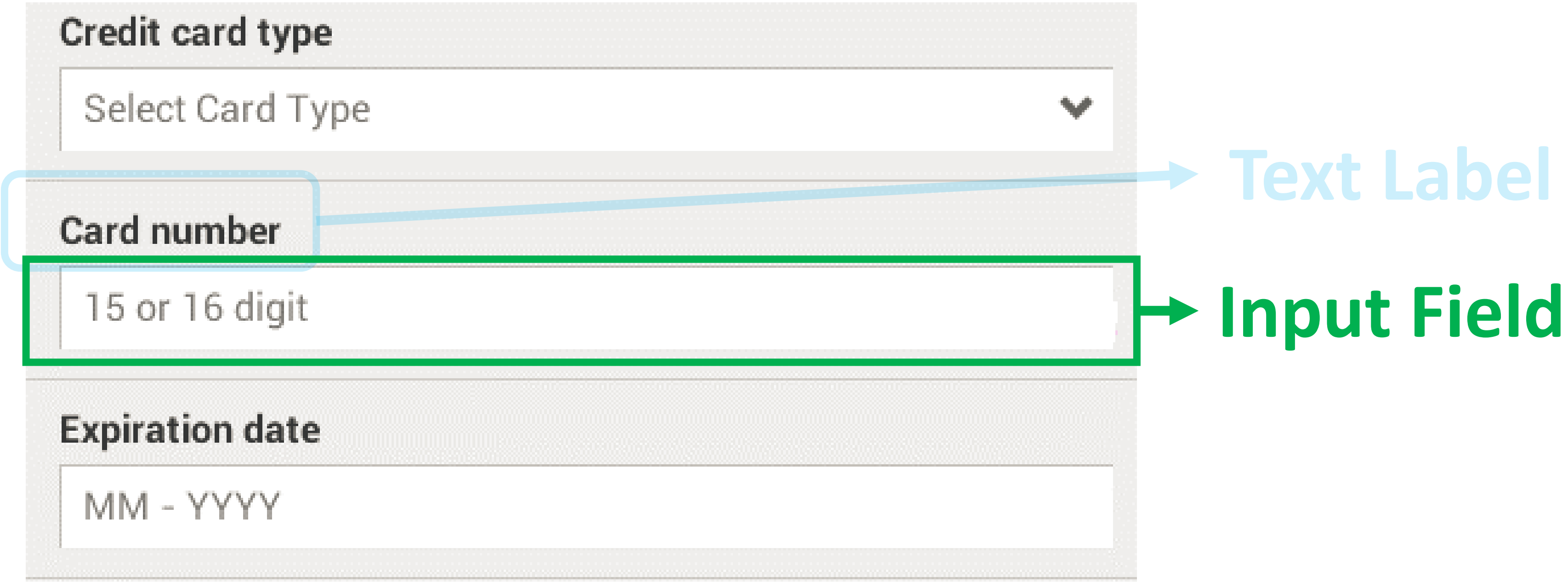
Text Label

Background - UI



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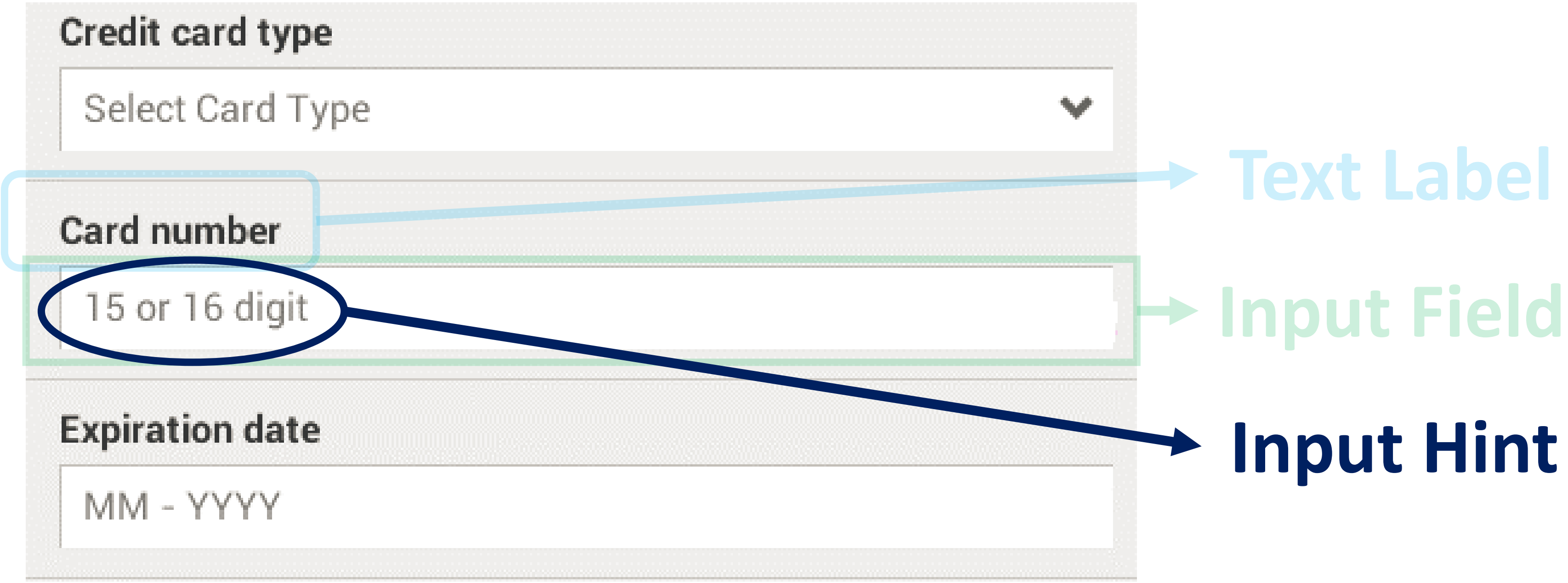
Background - UI



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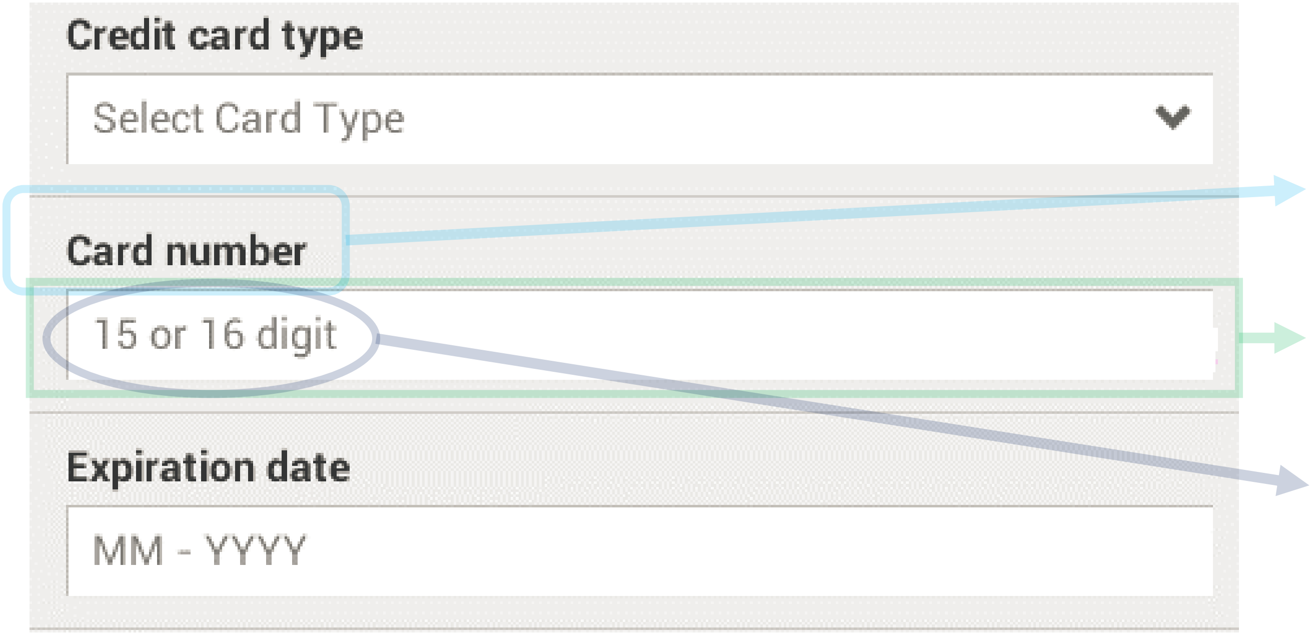

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Text Label

Input Field

Input Hint

Widget

Background – Layout File

- A piece in an Android layout example.

```
<EditText

    android:id="@+id/pwd“

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  android:inputType=“textPassword”/>
```
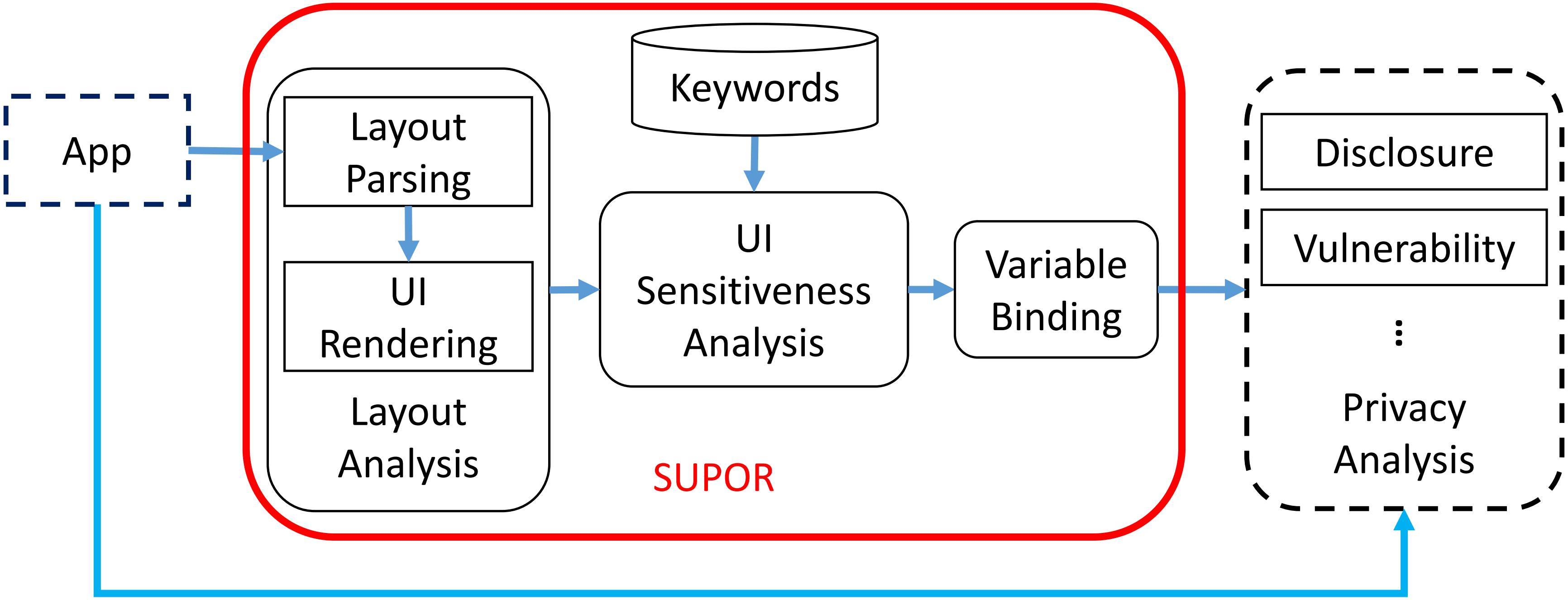

Identifier

Interesting Attribute

Overview of SUPOR



Parsing Layout

- We need to know which layout files contain input fields.

Is Sensitive User Input Detection Needed?

Layout file

Parsing Layout

- We need to know which layout files contain input fields.

Layout file

Is Sensitive User Input Detection Needed?

layout contains input fields ✓

✗ layout doesn’t contain input fields

Rendering UI

- Statically render layout files to UIs as users look at on smartphones via tools like ADT in Android.

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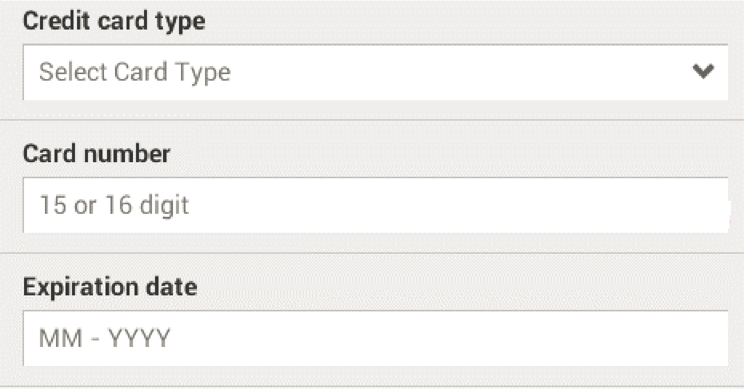
Layout file A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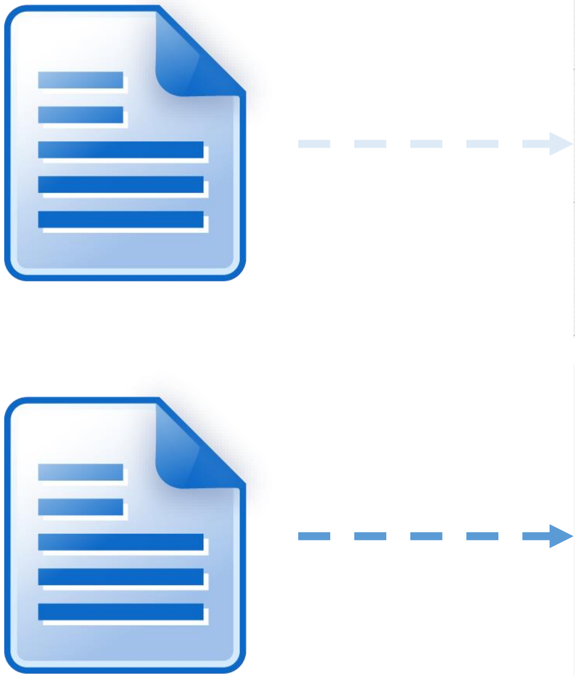
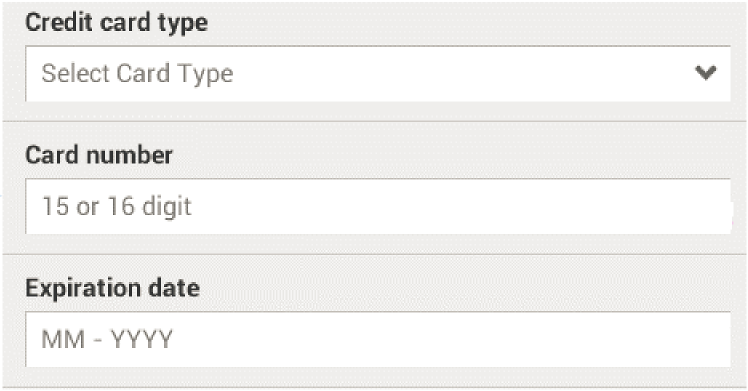
Rendering UI

- Statically render layout files to UIs as users look at on smartphones via tools like ADT in Android.

Layout file A

Layout file B





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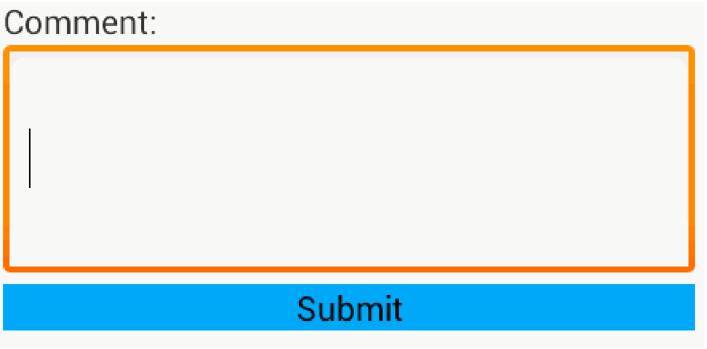
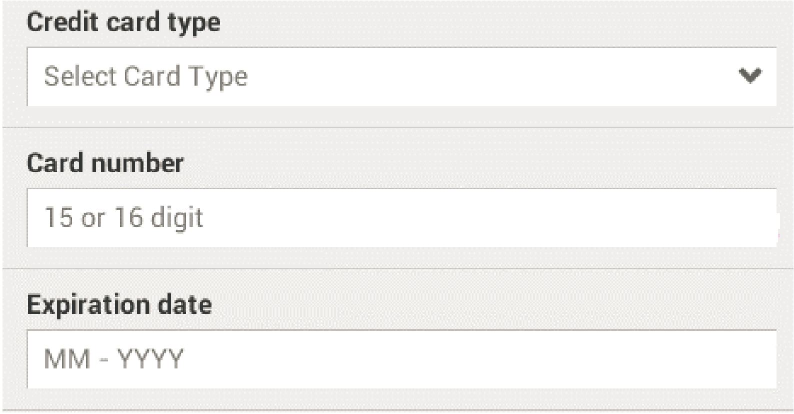


Comment:

Extracting Information



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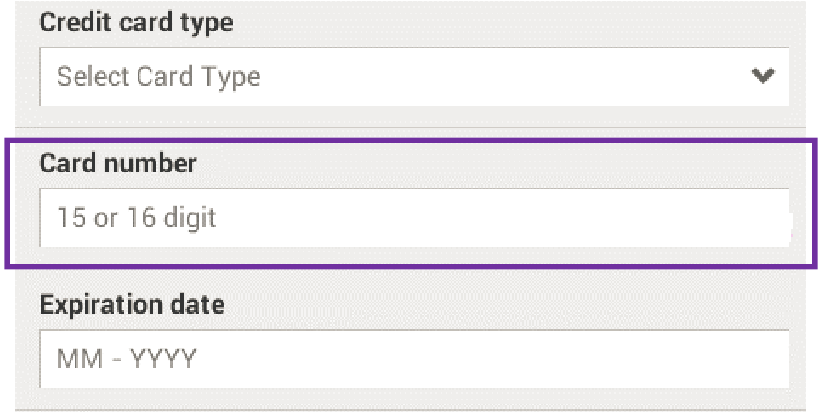

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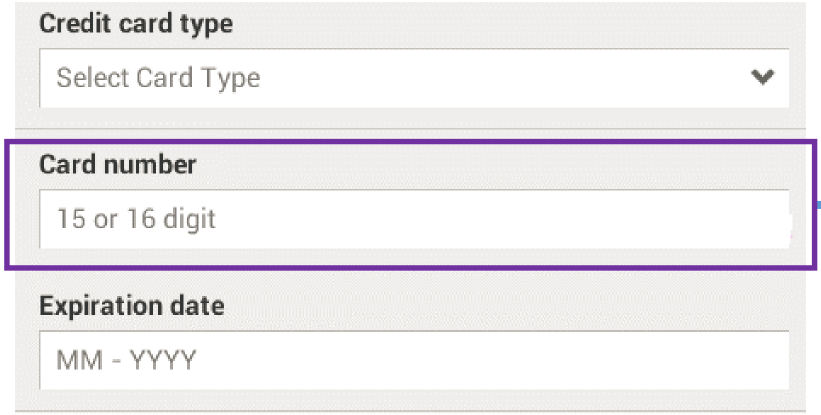
Extracting Information



Credit card type

Select Card Type

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Collect information

- Text Label
  - Text: Card Number
  - Coordinates: [16, 231, 109, 249]
- Input Field
  - Hint: 15 or 16 digit
  - Coordinates: [16, 249, 464, 297]

UI Sensitiveness Analysis

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Sensitive Attributes
in Layout Files

```
<EditText android:id="@+id/pwd‟
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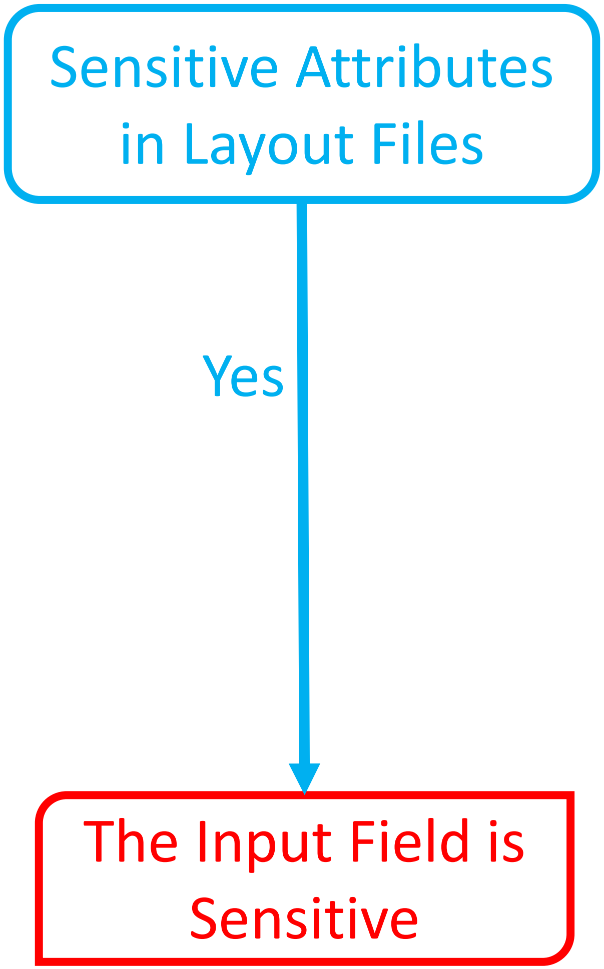
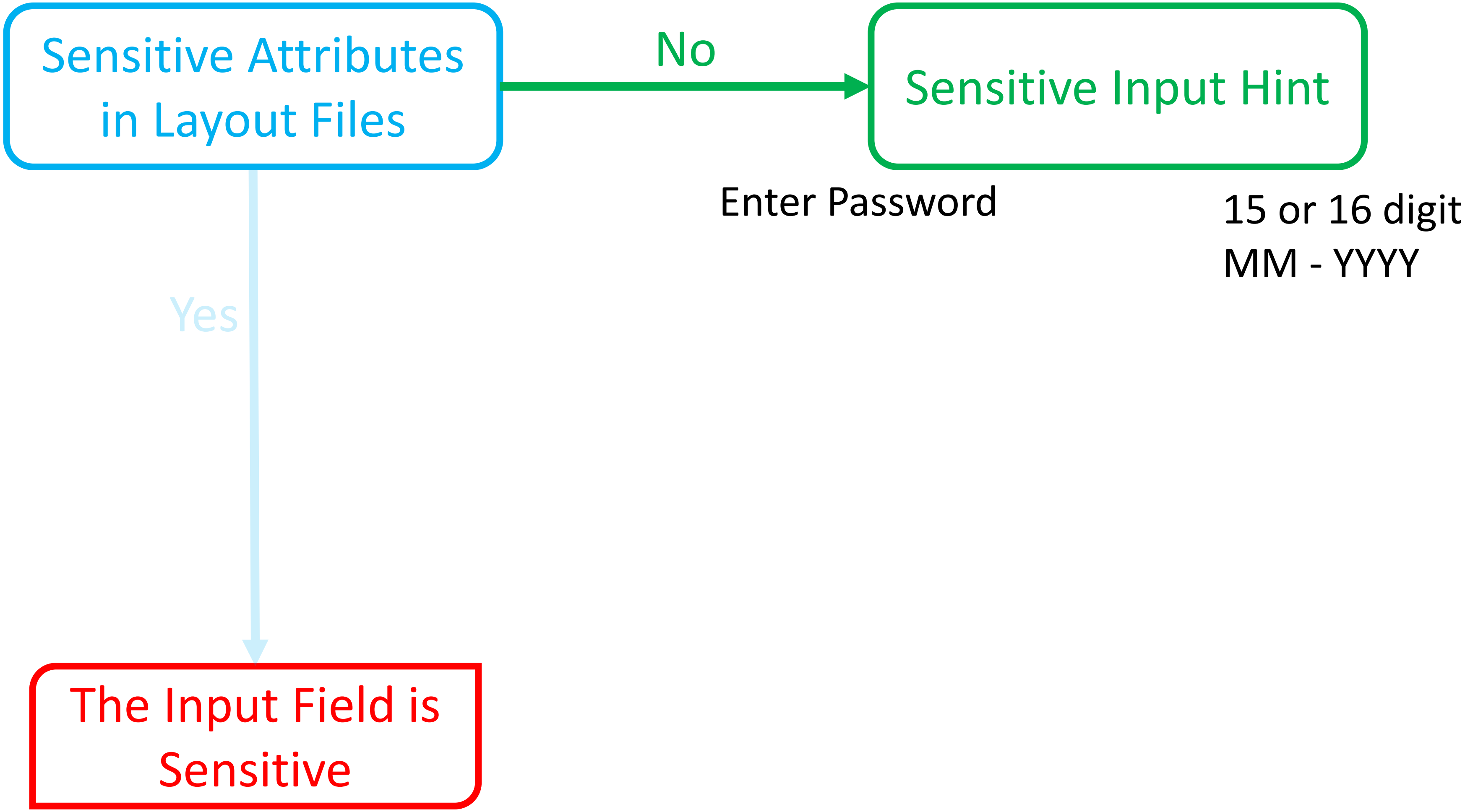


Sensitive Attributes in Layout Files

Yes

The Input Field is Sensitive

UI Sensitiveness Analysis



Sensitive Attributes in Layout Files

No

Sensitive Input Hint

Enter Password

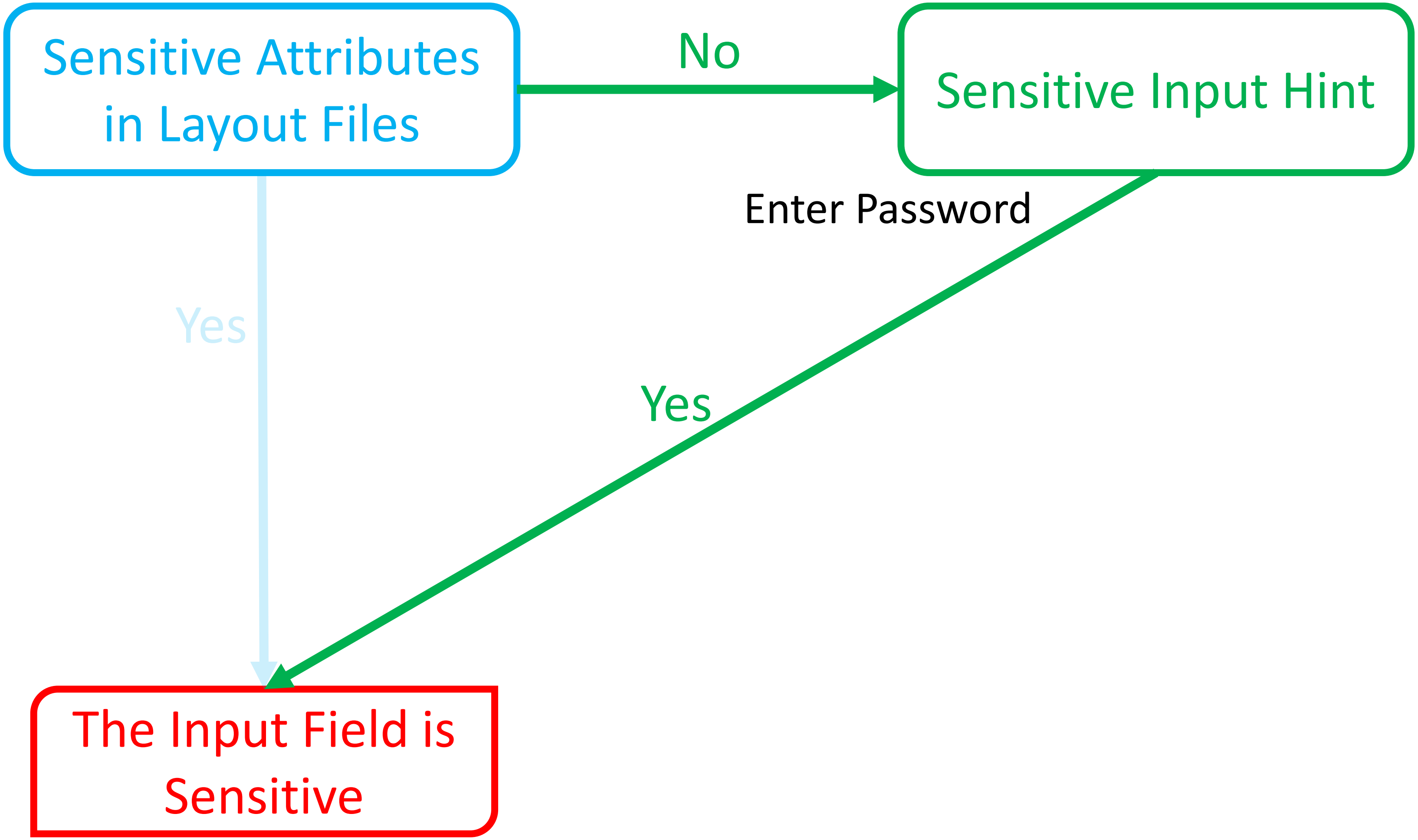
15 or 16 digit

MM - YYYY

Yes

The Input Field is Sensitive

UI Sensitiveness Analysis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Enter Password
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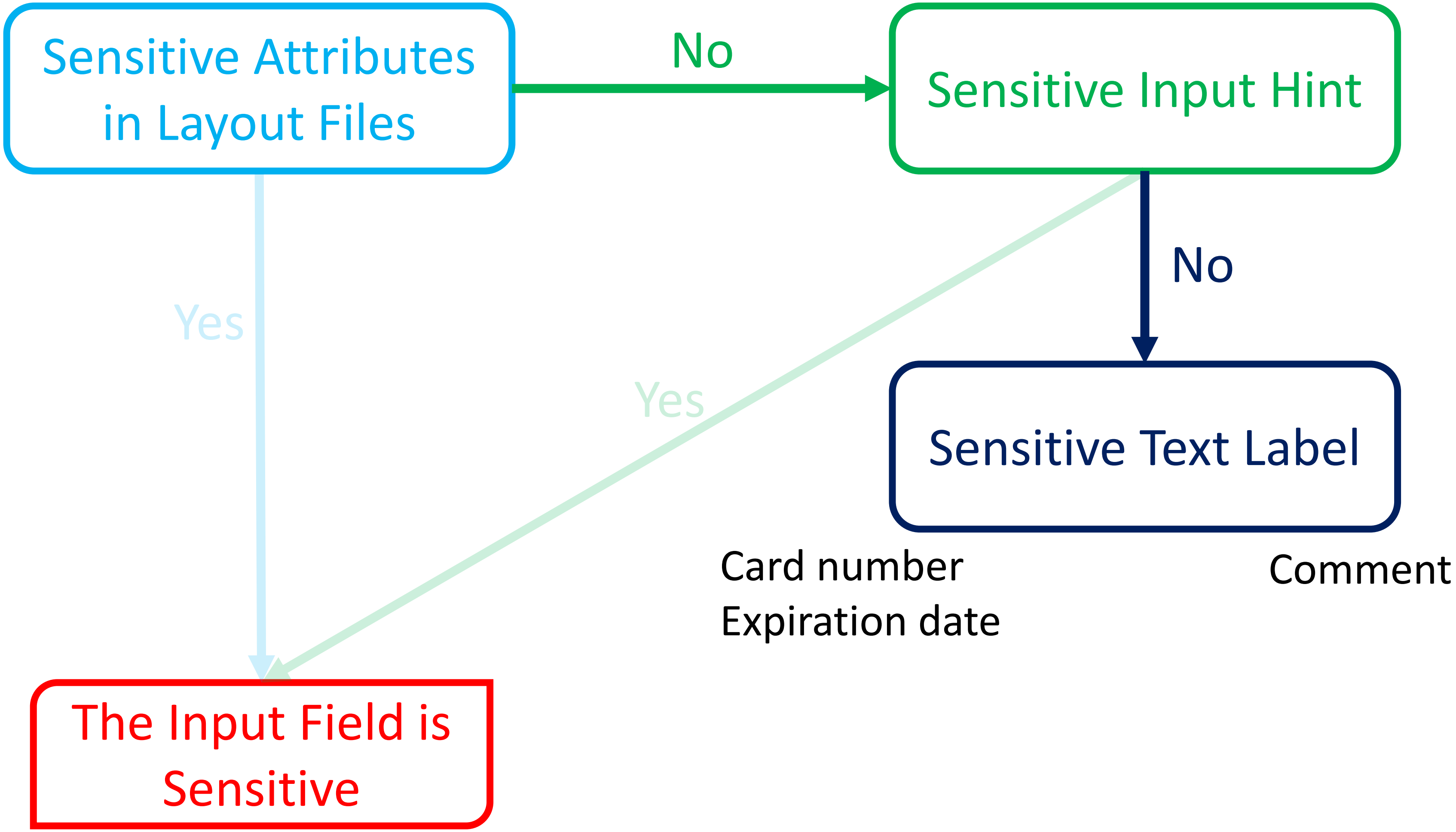
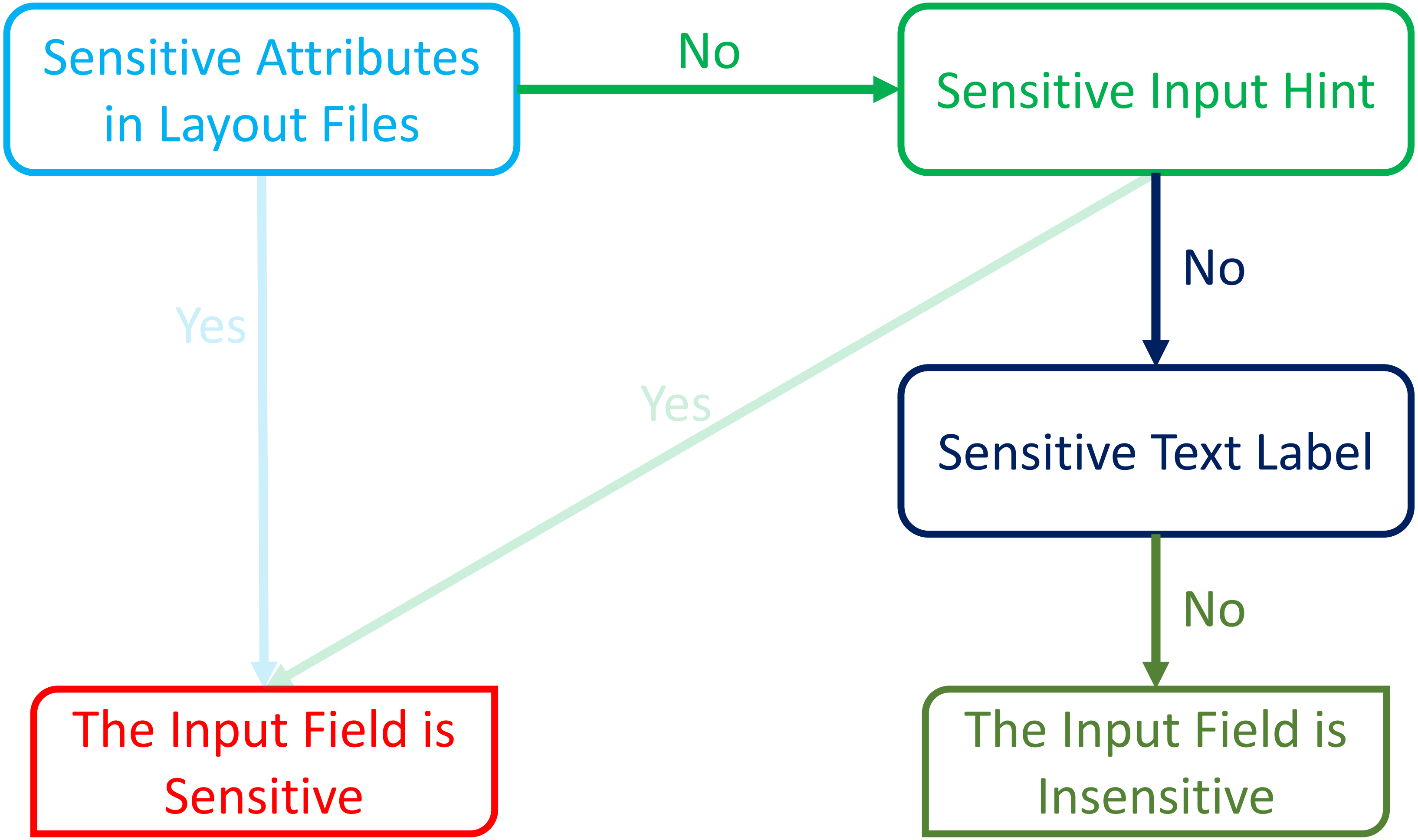


UI Sensitiveness Analysis



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No

Sensitive Input Hint

Yes

Yes

No

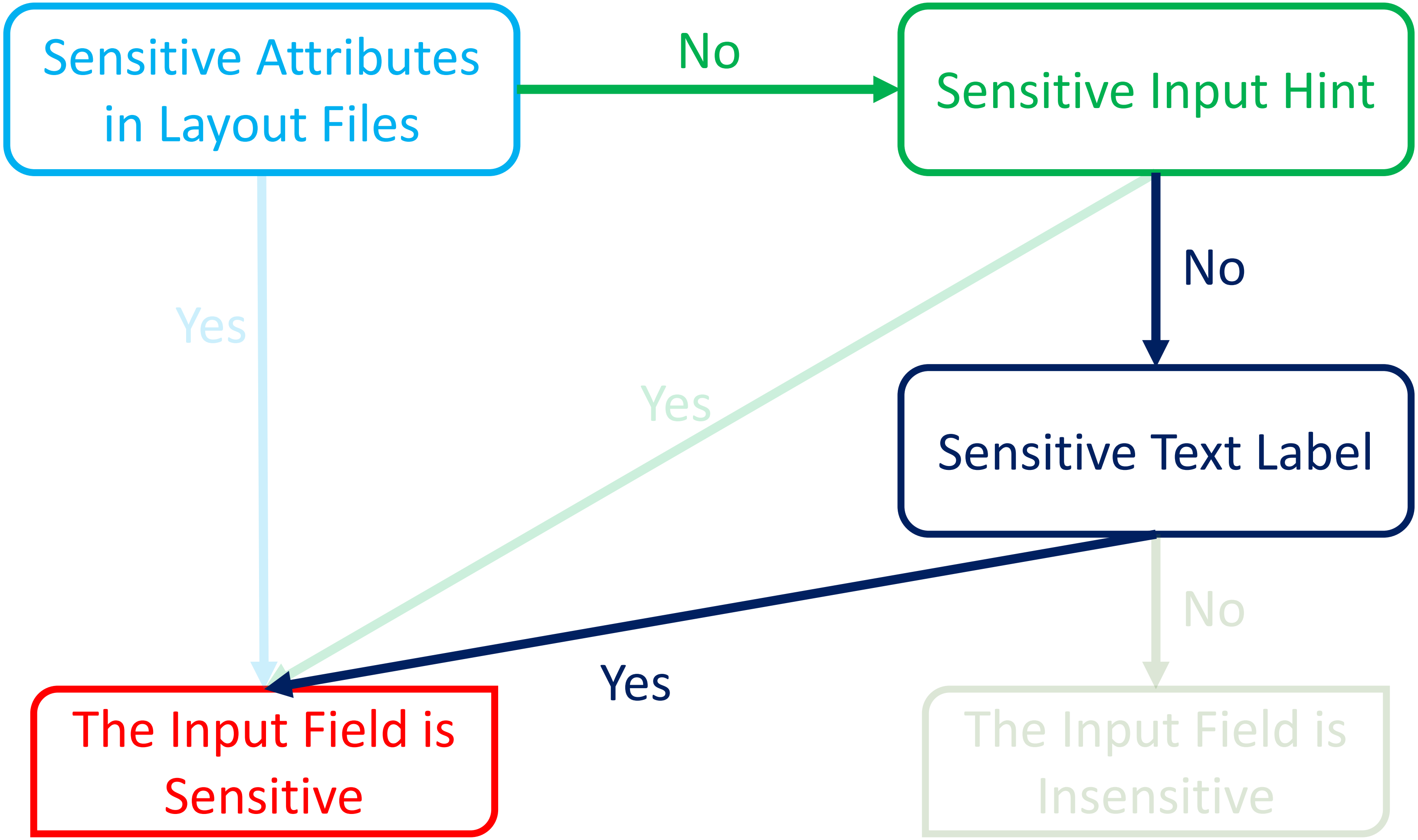
Sensitive Text Label

No

The Input Field is Sensitive

The Input Field is Insensitive

UI Sensitiveness Analysis



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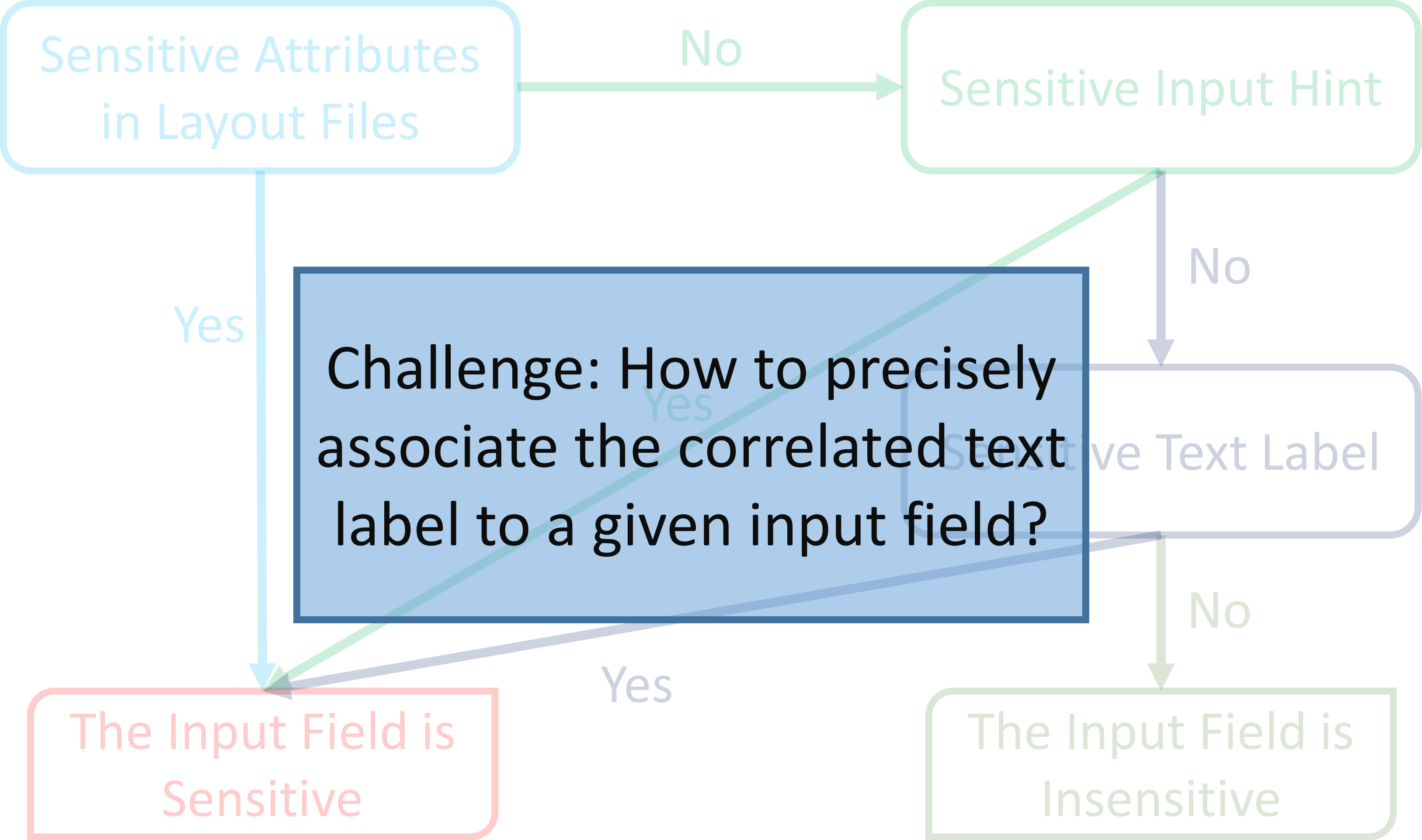
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The Input Field is Sensitive
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Challenge: How to precisely associate the correlated text label to a given input field?

Associating Labels (1)

- Intuition: labels at different positions relative to the input field have different probabilities to be correlated.

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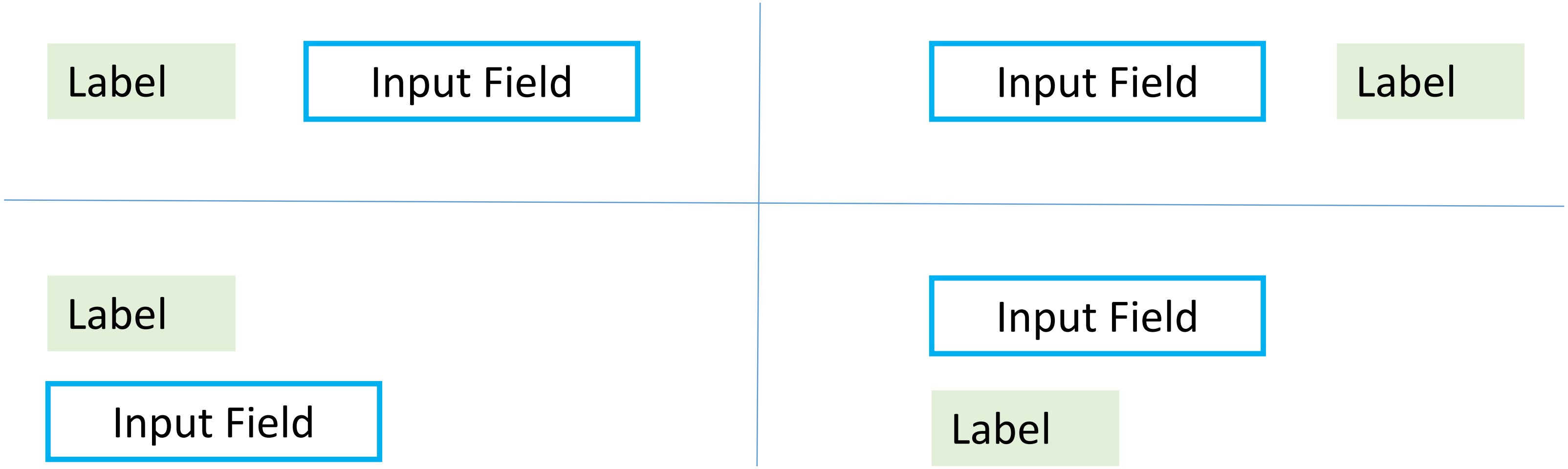

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- Assign position-based weights based on empirical observations
    - The **smaller** the weight, the **closer** the correlation

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0.8	Input Field	9
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Associating Labels (2)

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4	2	8
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Associating Labels (3)

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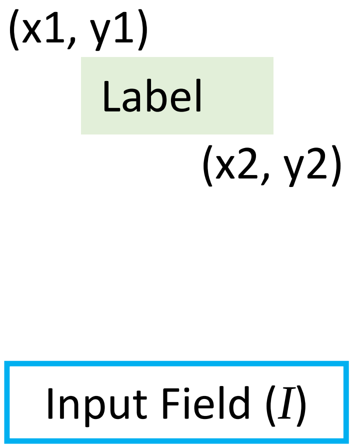


(x1, y1)

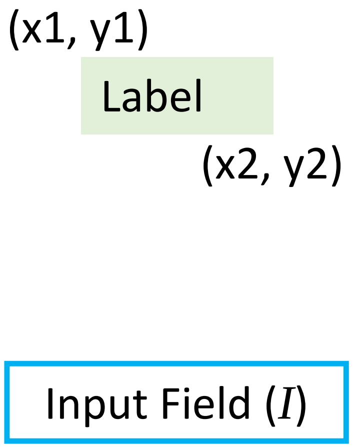
Label

(x2, y2)

Input Field (I)

Associating Labels (3)

- Geometry-based correlation score computation



(x1, y1)

Label

(x2, y2)

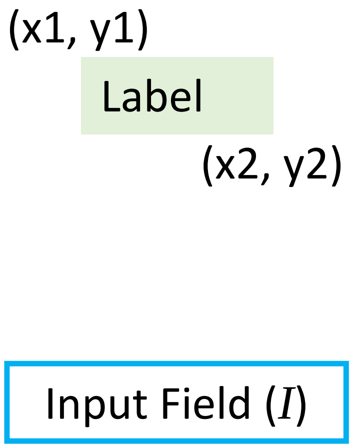
Input Field (*I*)

➢ For each pixel (*x*,*y*) in a text label

- *distance(I, x, y) * posWeight(I, x, y)*

Associating Labels (3)

- Geometry-based correlation score computation



➢ For each pixel (x,y) in a text label
  - $distance(I, x, y) * posWeight(I, x, y)$

➢ Average the correlation score for the text label

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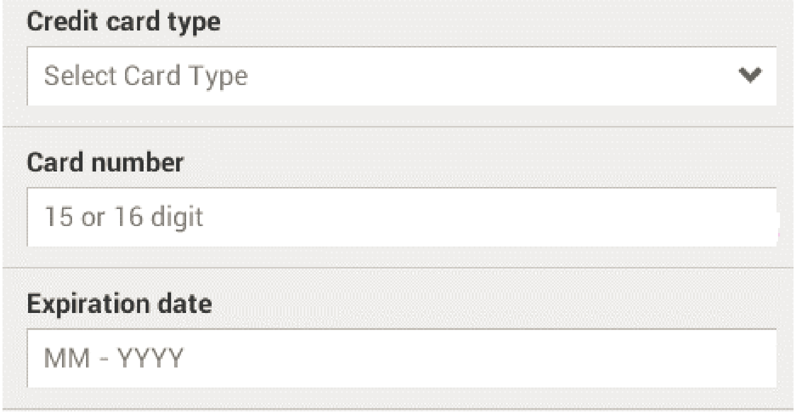

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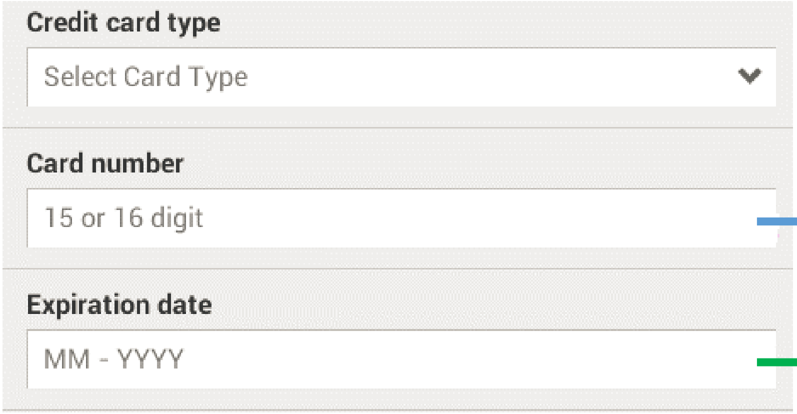
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Correlation scores

Label	**Number Field**	**Date Field**
Credit card type	265.57	456.42
Card number	**76.47**	271.23
Expiration date	205.29	**75.40**

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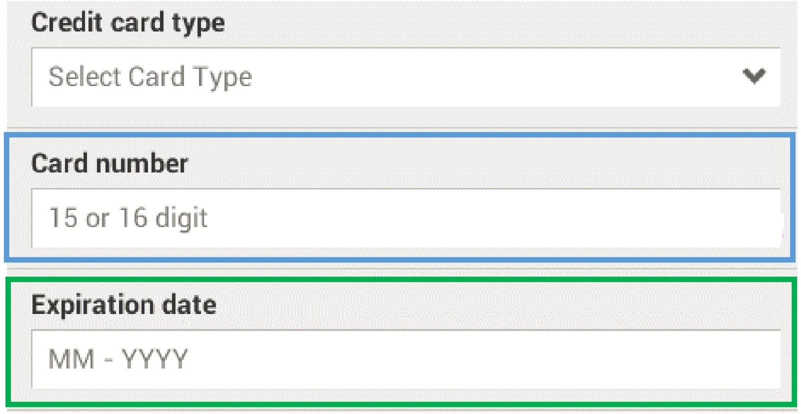
- Find out the label with the smallest correlation score among all potential labels for a given input field



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Label	**Number Field**	**Date Field**
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Determining Sensitiveness (1)

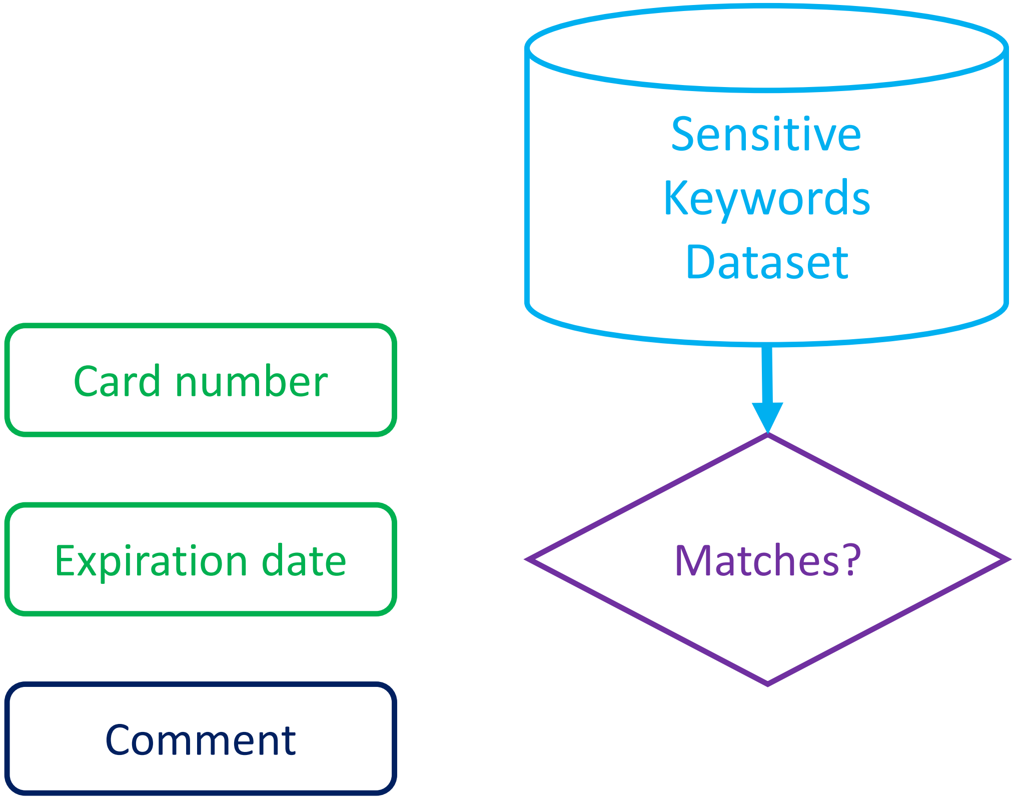
Card number

Expiration date

Comment

Determining Sensitiveness (1)

- Keyword matching approach



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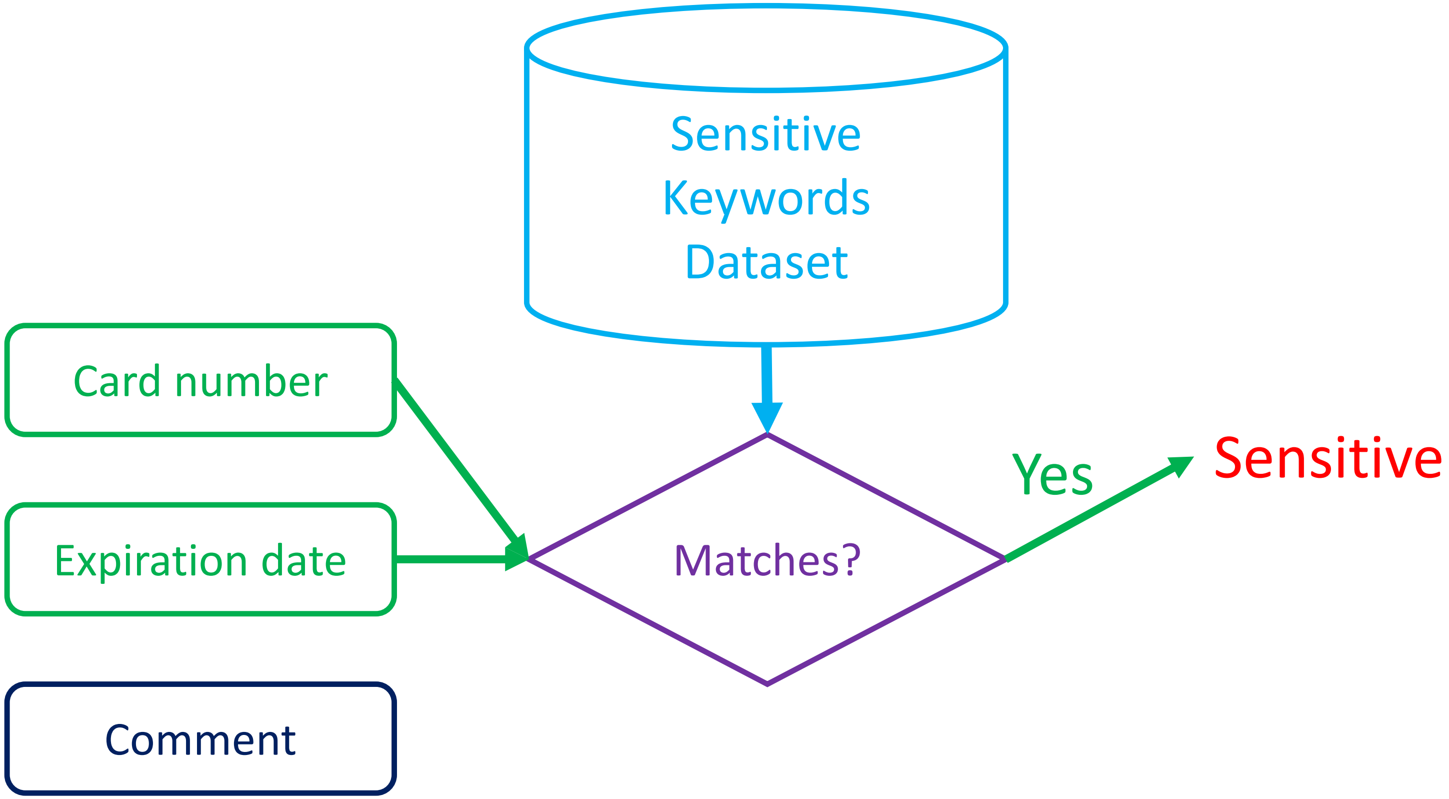

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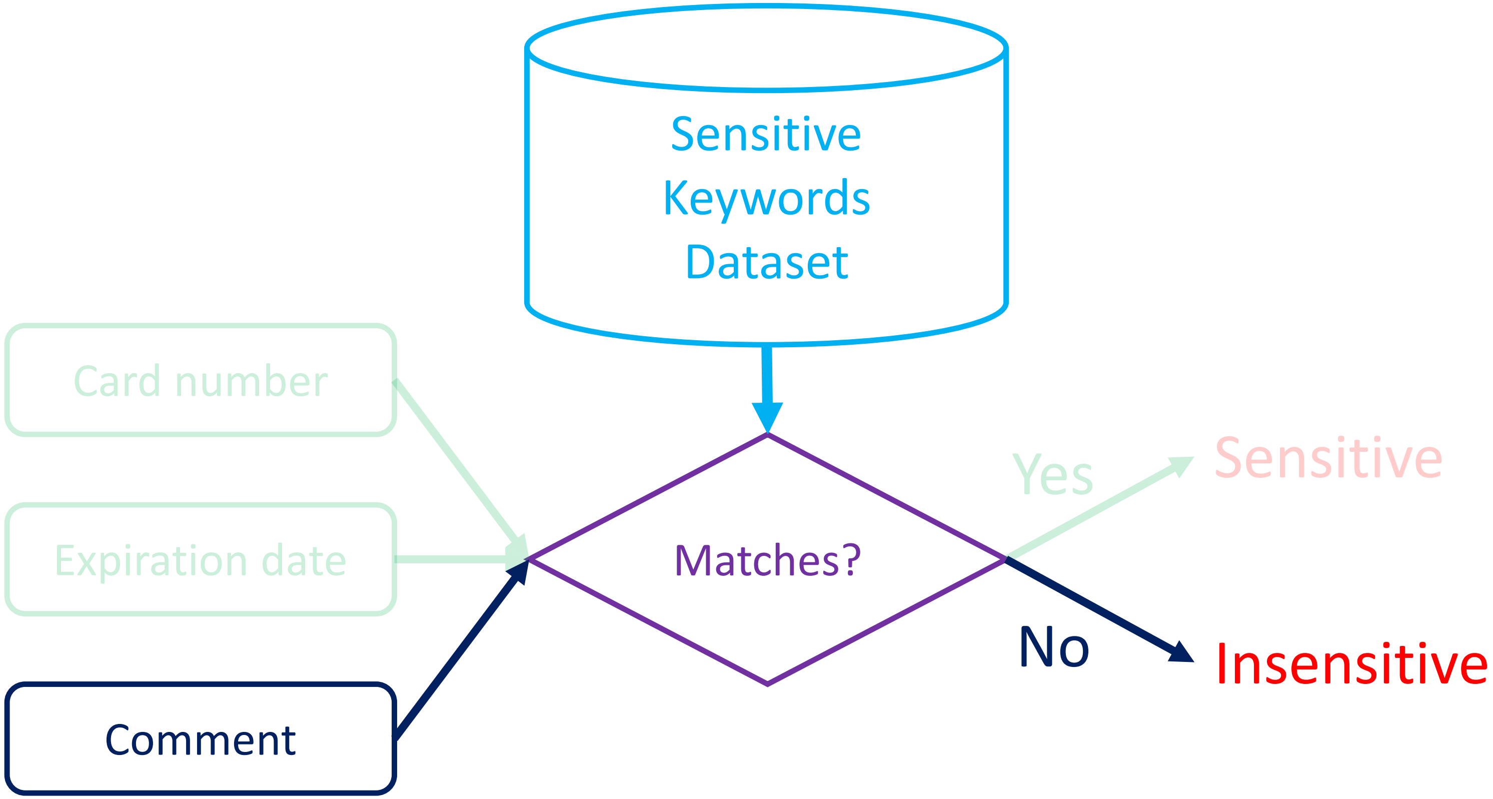

Determining Sensitiveness (2)

- Why is keyword matching approach effective?

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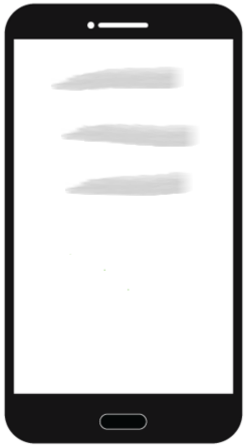

- **Small** screen and **short** phrases or sentences

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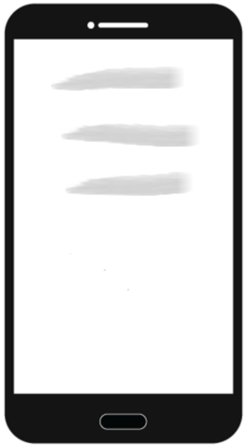
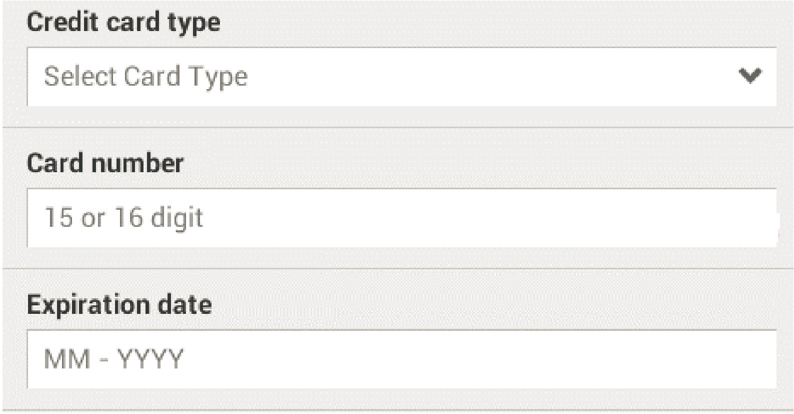
- Why is keyword matching approach effective?



- **Small** screen and **short** phrases or sentences
- We only analyze the **most relevant** text label

Binding Variables (1)



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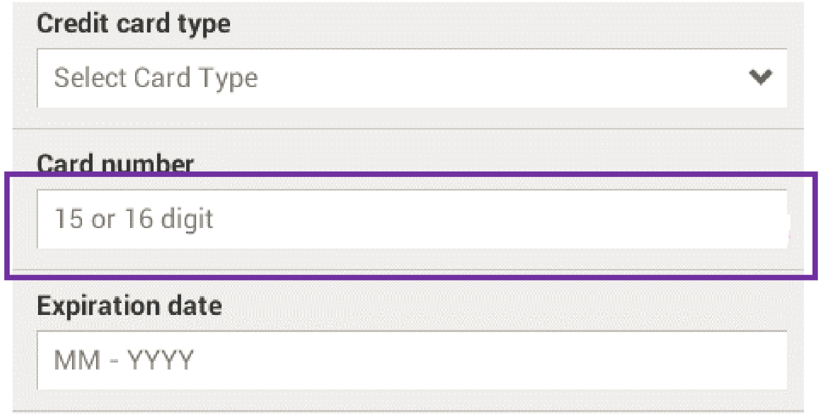

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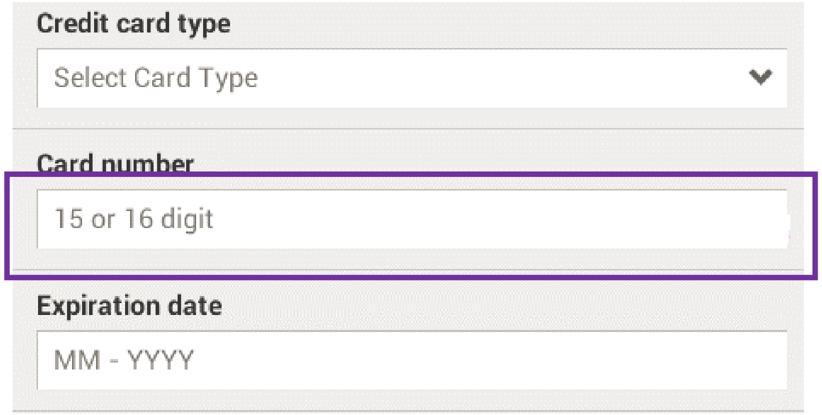
MM - YYYY

Binding Variables (1)



Credit card type

Select Card Type

Card number

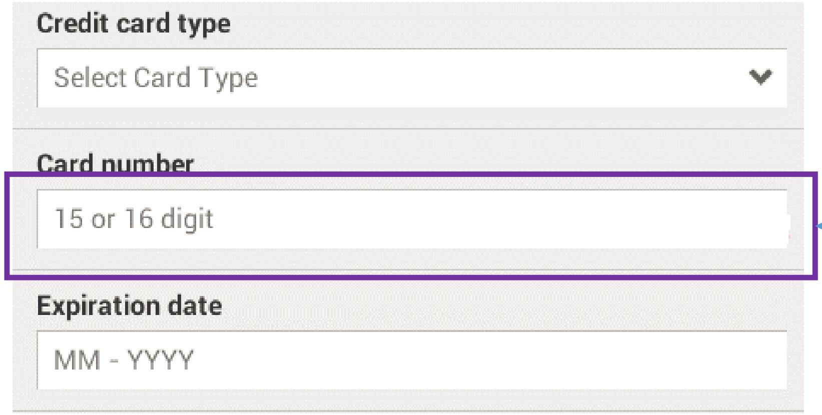
15 or 16 digit

Expiration date

MM - YYYY

```
Widget txtCN = findViewById(X);
Data cnum = txtCN.getText();
// use of “cnum”
```

Binding Variables (1)



Credit card type

Select Card Type

Card number

15 or 16 digit

Expiration date

MM - YYYY

Identifier: X

```
Widget txtCN = findViewById(X);
Data cnum = txtCN.getText();
// use of "cnum"
```

Binding Variables (2)

- Challenge: different widgets within one apps have the same identifier

```
<TextView android:text= =“Card Number‟ />
<EditText android:id=“@+id/input1‟ … />
…
```

```
<TextView android:text= =“Search‟ />
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…
```

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<EditText android:id=“@+id/input1‟ … />
…
```

```
txtInput1 = this.findViewById(input1);
```

```
txtInput2 = this.findViewById(input1);
```

Binding Variables (2)

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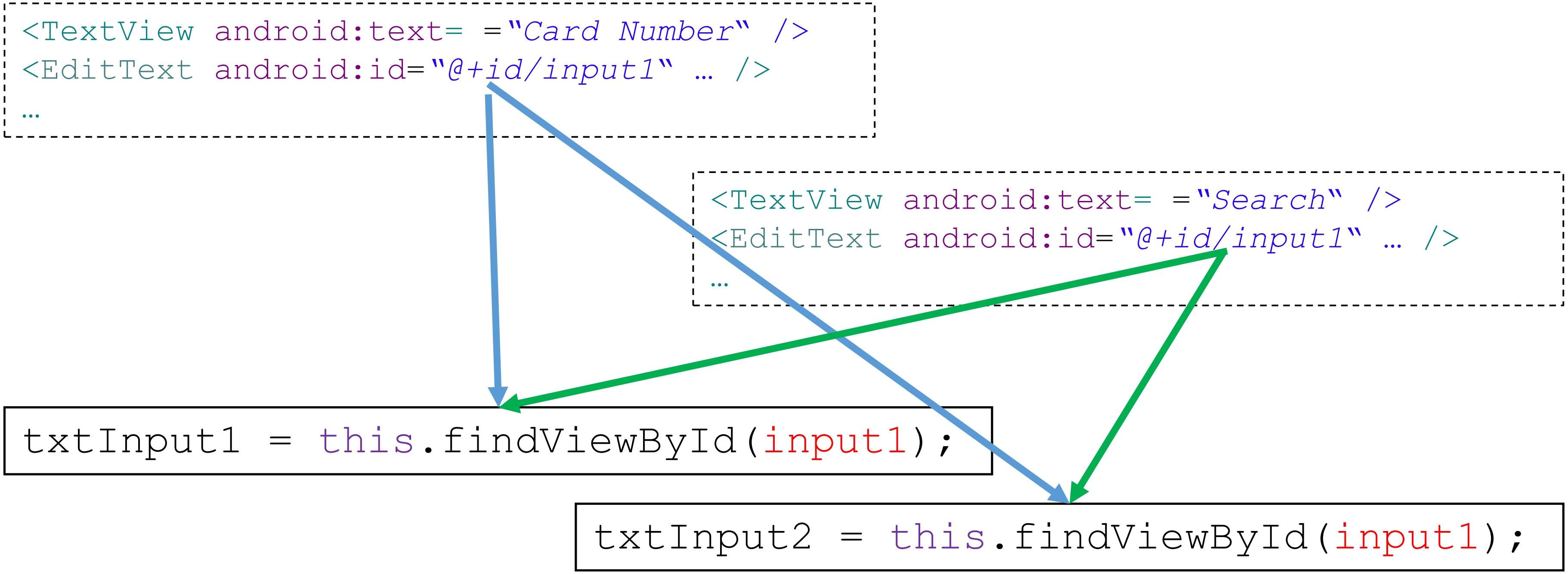

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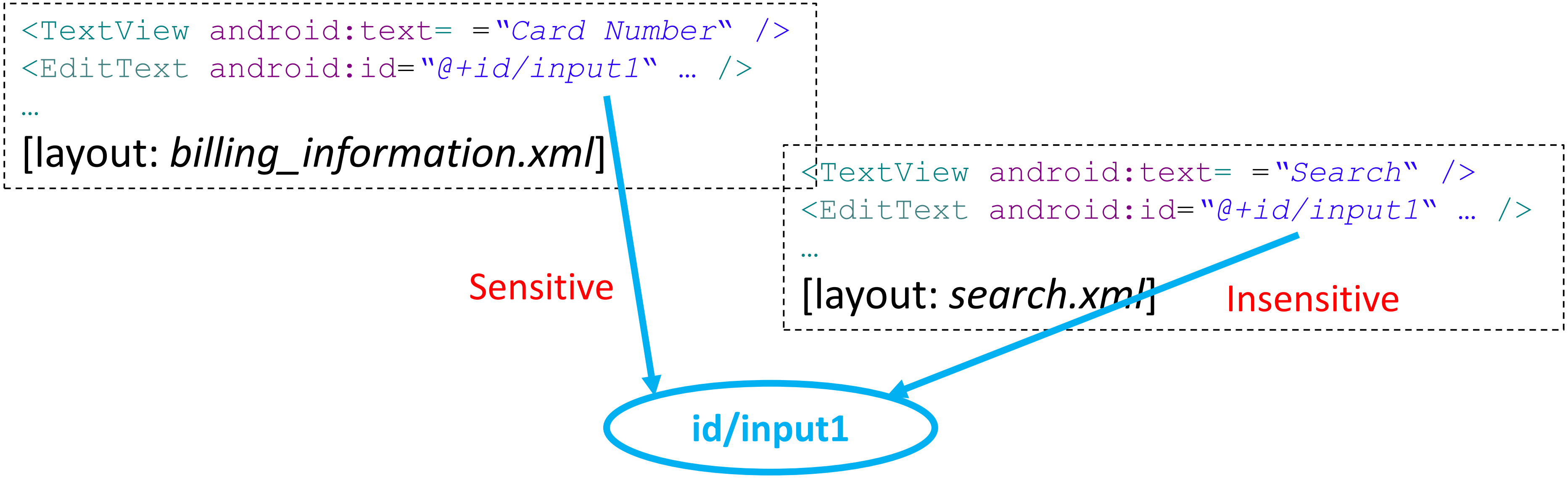
<TextView android:text= =“Card Number‟ />
<EditText android:id=“@+id/input1‟ … />
…
```

```
<TextView android:text= =“Search‟ />
<EditText android:id=“@+id/input1‟ … />
…
```

```
txtInput1 = this.findViewById(input1);
```

```
txtInput2 = this.findViewById(input1);
```

Binding Variables (3)



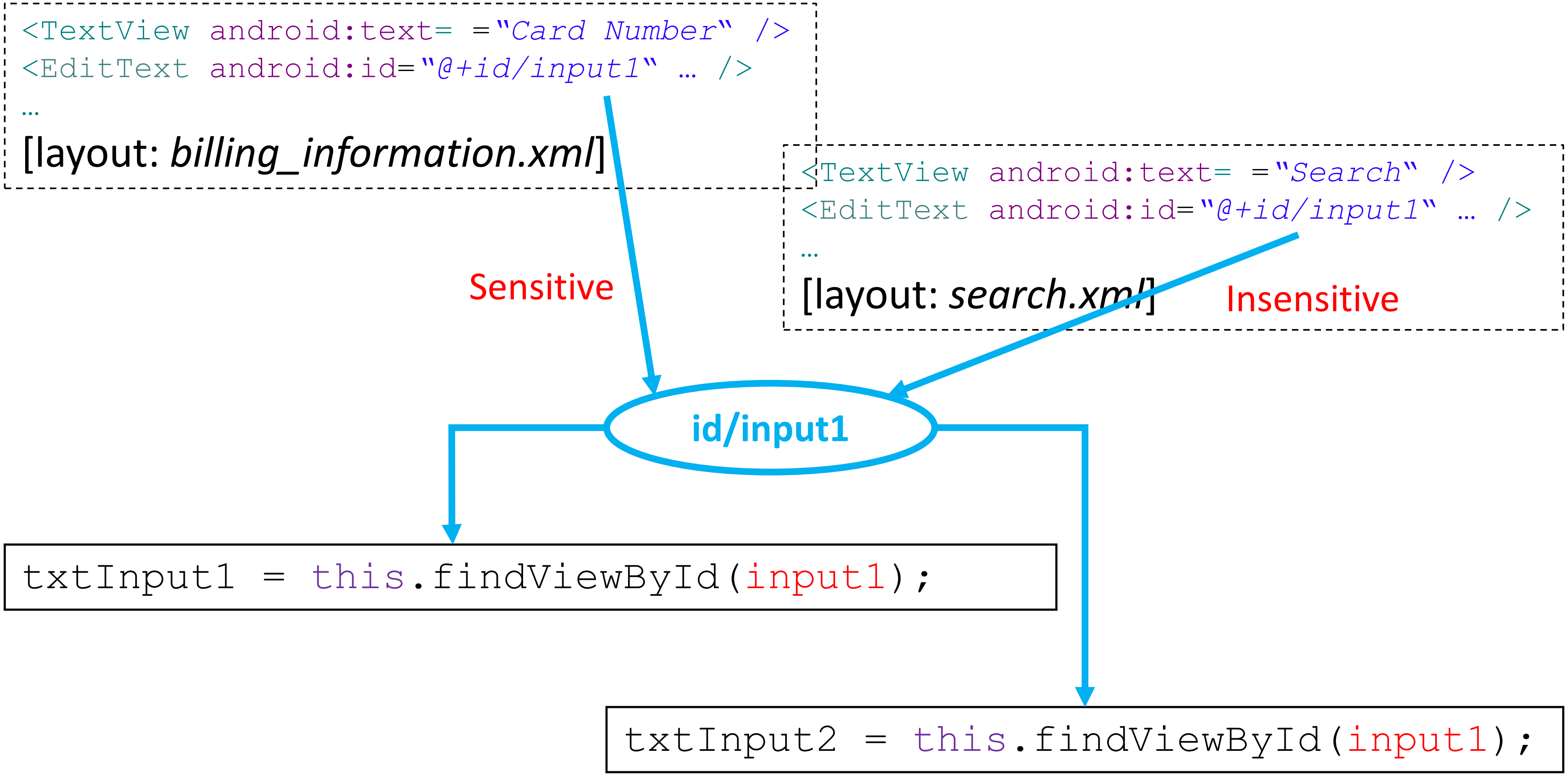
```
<TextView android:text= ="Card Number" />
<EditText android:id="@+id/input1" … />
…
```

[layout: *billing_information.xml*]

```
<TextView android:text= ="Search" />
<EditText android:id="@+id/input1" … />
…
```

[layout: *search.xml*]

Binding Variables (3)



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…
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[layout: *billing_information.xml*]

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```
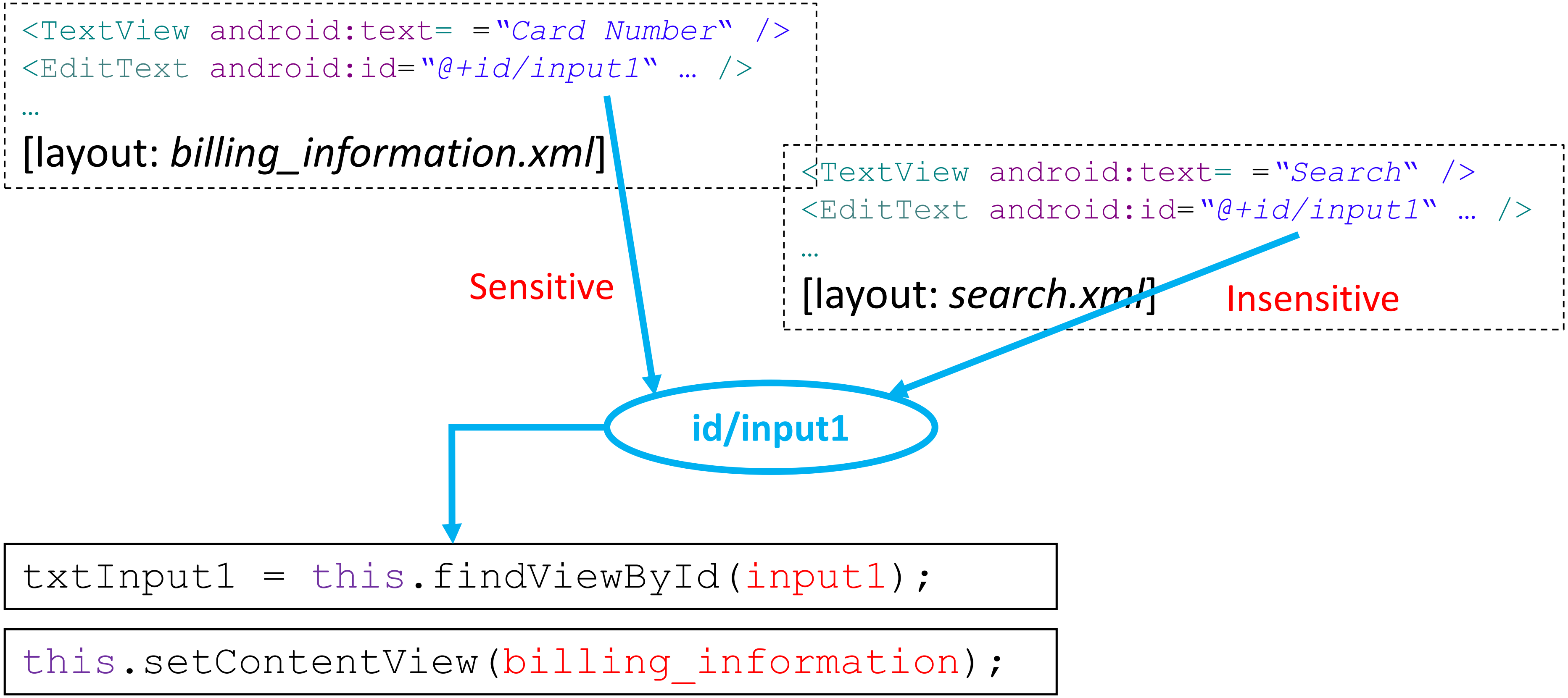

Binding Variables (3)



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[layout: *billing_information.xml*]

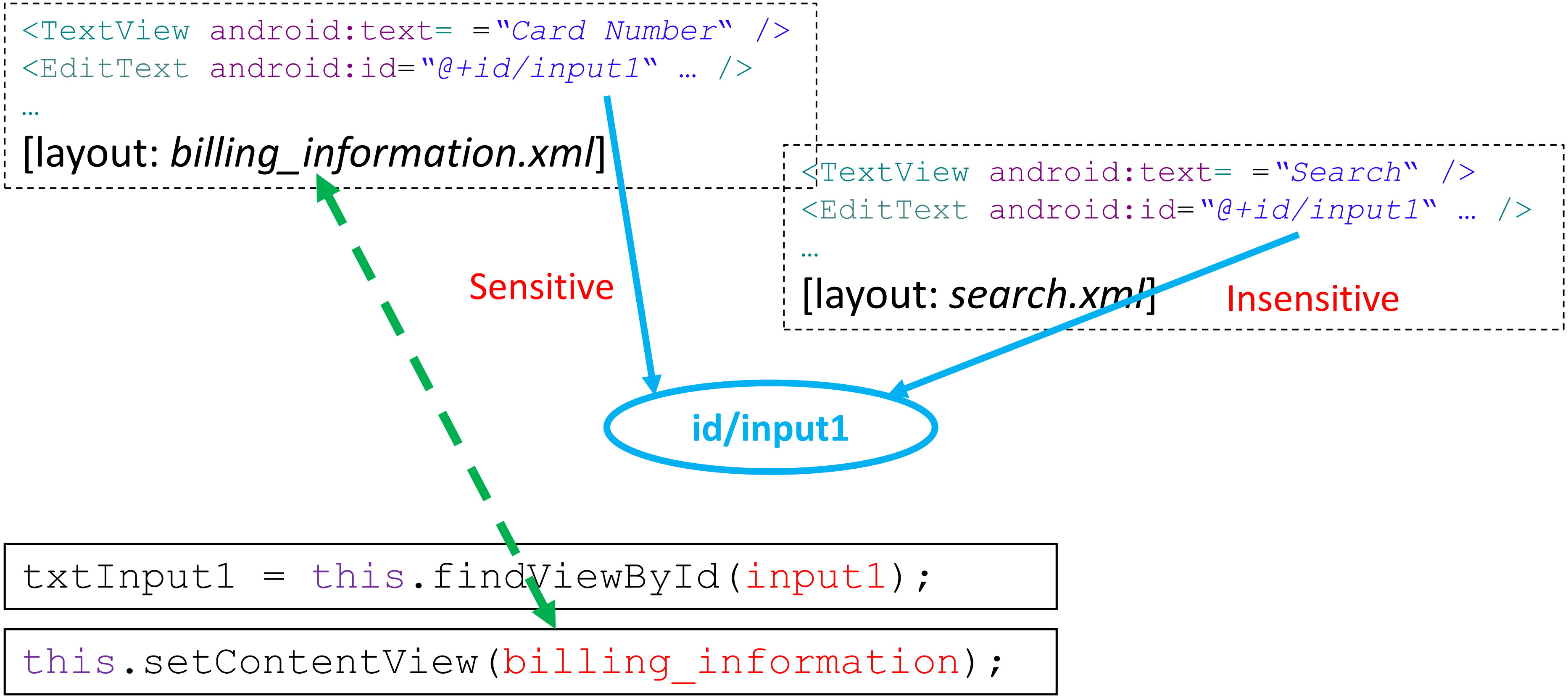
```
<TextView android:text= =“Search‟ />
<EditText android:id=“@+id/input1‟ … />
…
```

[layout: *search.xml*]

```
txtInput1 = this.findViewById(input1);
```

```
this.setContentView(billing_information);
```

Binding Variables (3)



```
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…
```

[layout: *billing_information.xml*]

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<EditText android:id="@+id/input1" … />
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[layout: *search.xml*]

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```

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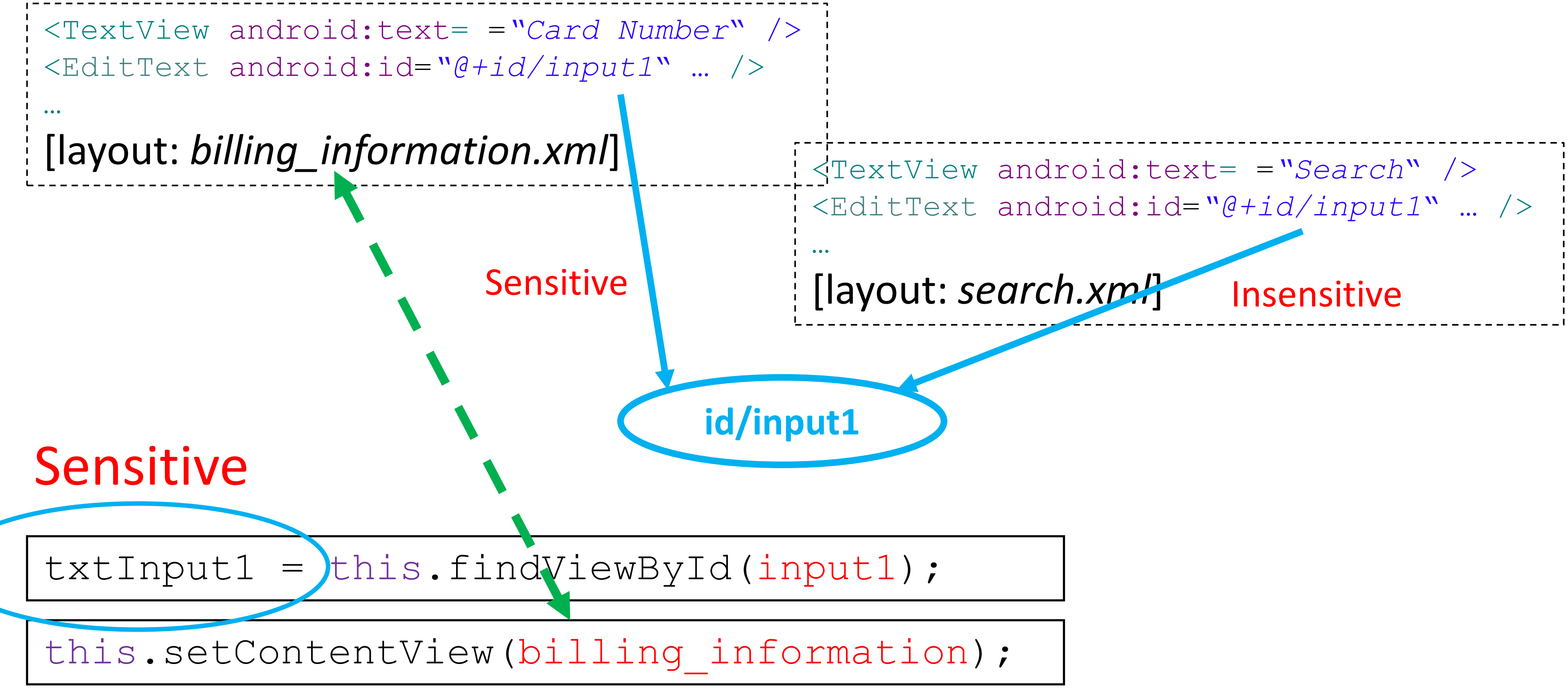

```
<TextView android:text= ="Card Number" />
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[layout: *billing_information.xml*]

```
<TextView android:text= ="Search" />
<EditText android:id="@+id/input1" … />
…
```

[layout: *search.xml*]

Sensitive

Insensitive

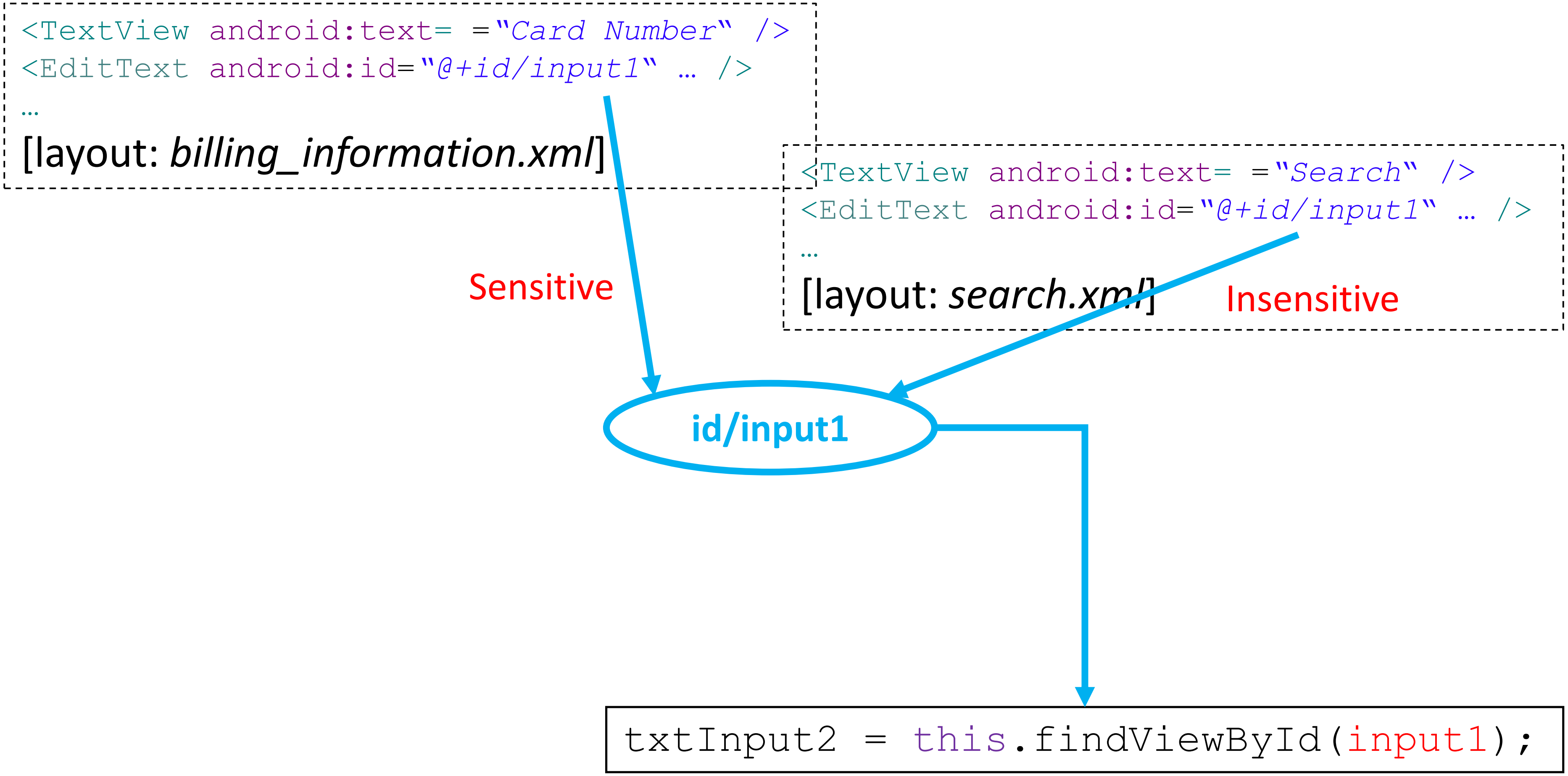
id/input1

Sensitive

```
txtInput1 = this.findViewById(input1);
```

```
this.setContentView(billing_information);
```

Binding Variables (3)



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…
```

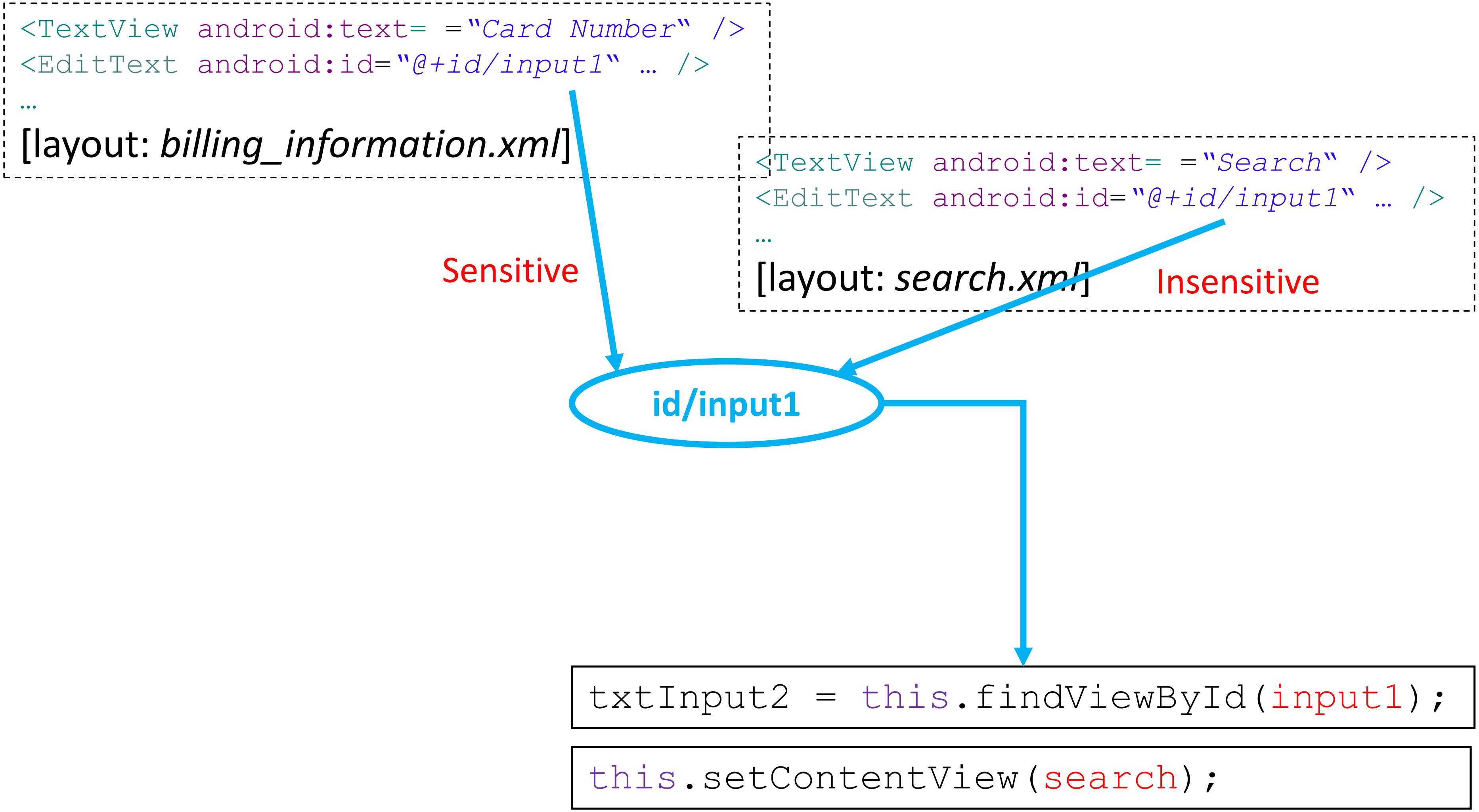
[layout: *billing_information.xml*]

```
<TextView android:text= =“Search‟ />
<EditText android:id=“@+id/input1‟ … />
…
```

[layout: *search.xml*]

```
txtInput2 = this.findViewById(input1);
```

Binding Variables (3)



```
<TextView android:text= ="Card Number" />
<EditText android:id="@+id/input1" … />
…
```

[layout: *billing_information.xml*]

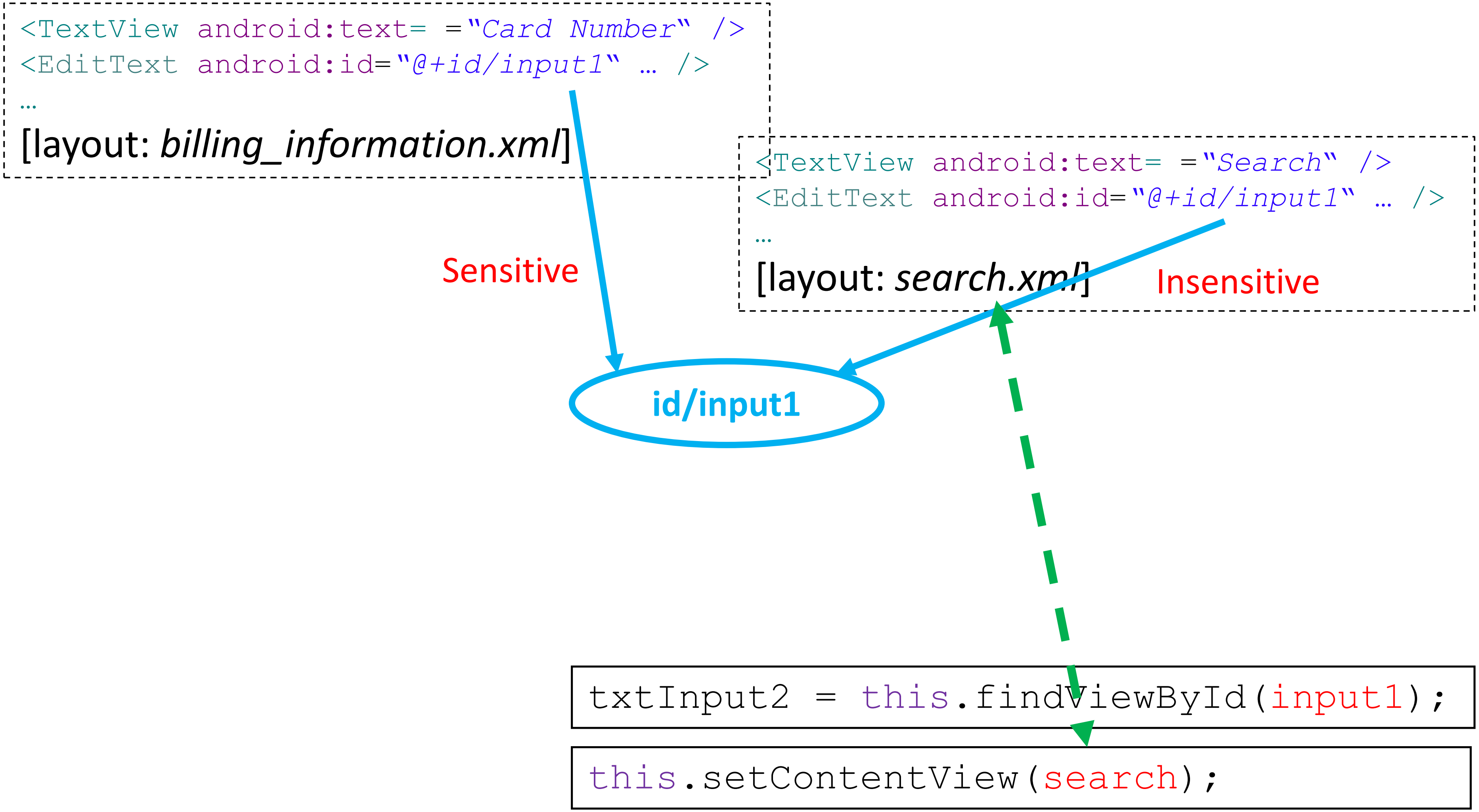
```
<TextView android:text= ="Search" />
<EditText android:id="@+id/input1" … />
…
```

[layout: *search.xml*]

```
txtInput2 = this.findViewById(input1);
```

```
this.setContentView(search);
```

Binding Variables (3)



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[layout: *billing_information.xml*]

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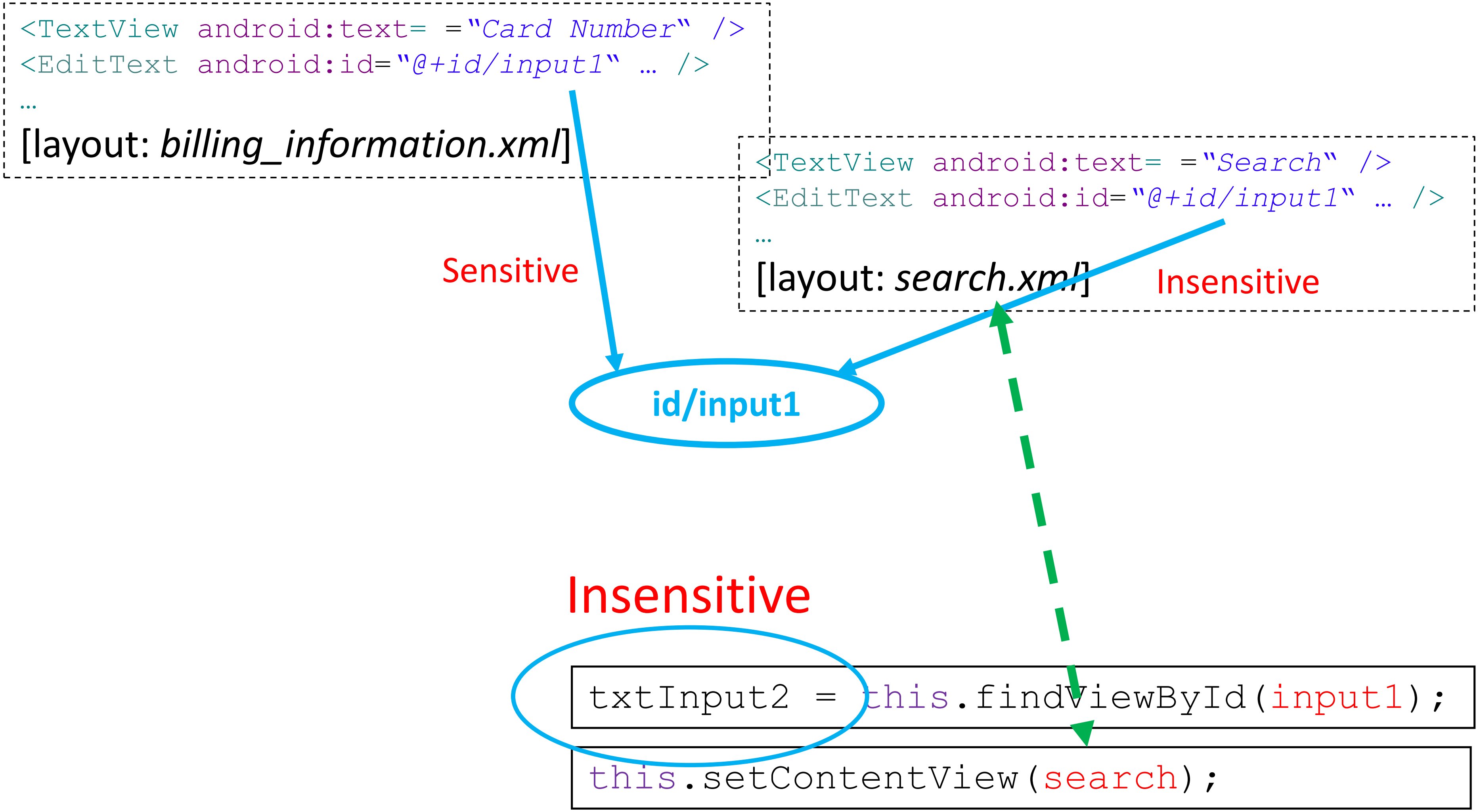

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[layout: *billing_information.xml*]

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[layout: *search.xml*]

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txtInput2 = this.findViewById(input1);
this.setContentView(search);
```
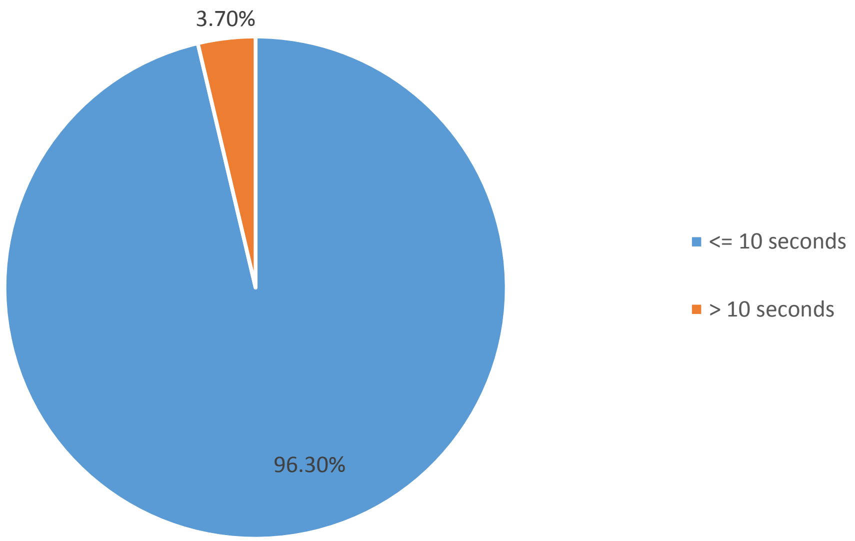

Implementation & Evaluation

- Implemented for Android apps and built on Dalysis[CHEX CCS’12], IBM WALA and ADT.
- Only input fields of type `EditText` are analyzed, i.e. other user inputs like checkbox are ignored.
- Implemented a sensitive user inputs disclosure detection system by combining SUPOR and static taint analysis
- 16,000 apps were evaluated

Evaluating UI Sensitiveness Analysis (1)

- 9,653 apps (60.33%) contains input fields
  - Performance:
    - Average analysis time is **5.7 seconds for one app**



Evaluating UI Sensitiveness Analysis (2)

- 9,653 apps (60.33%) contains input fields
  - Accuracy
    - Manually examined 40 apps . 115 layouts are rendered and 485 input fields are analyzed.
    - **TP**: sensitive user inputs are identified as sensitive
    - **FP**: insensitive user inputs are identified as sensitive
    - **FN**: sensitive user inputs are identified as insensitive

$$Recall = \frac{TP}{TP + FN} = 97.3\% \qquad Precision = \frac{TP}{TP + FP} = 97.3\%$$

- Causes for FN and FP
  - Insufficient context to identify sensitive keywords.
    - False negative: “Answer” vs “Security Answer”
    - False Positive: “Height” of an image file and for a human being

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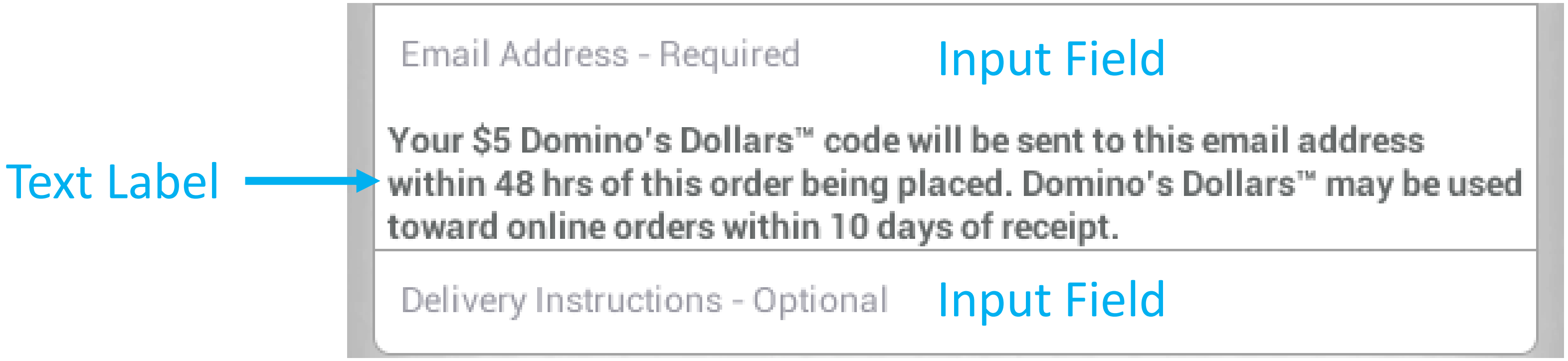

Email Address - Required

Input Field

Text Label

Your $5 Domino's Dollars™ code will be sent to this email address within 48 hrs of this order being placed. Domino's Dollars™ may be used toward online orders within 10 days of receipt.

Delivery Instructions - Optional

Input Field

- Causes for FN and FP
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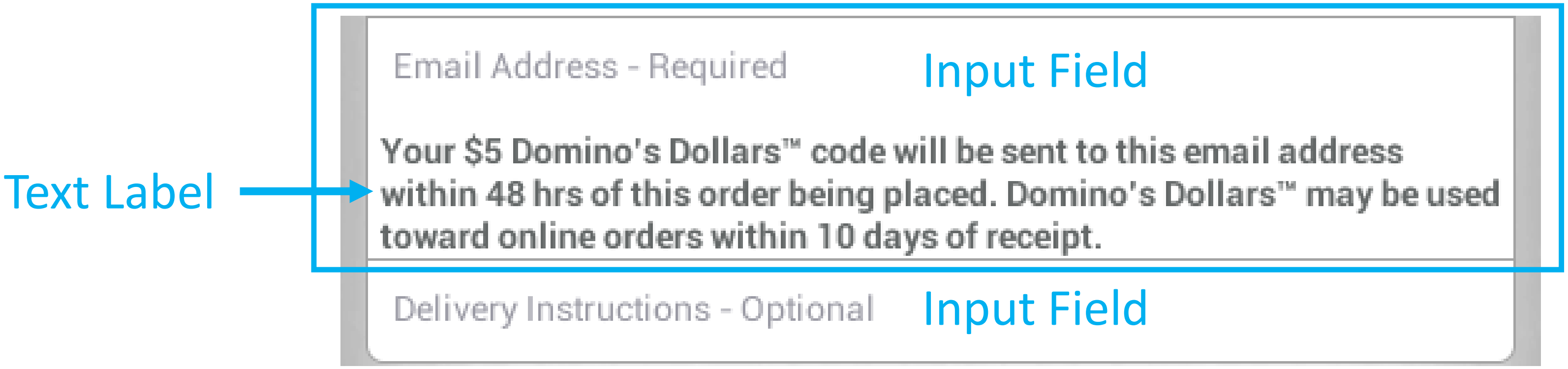

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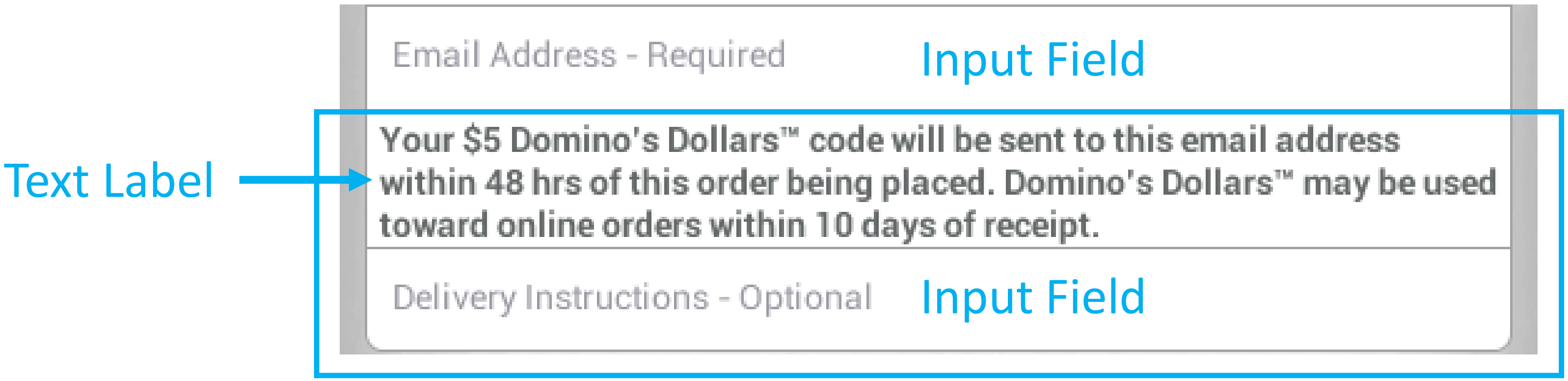

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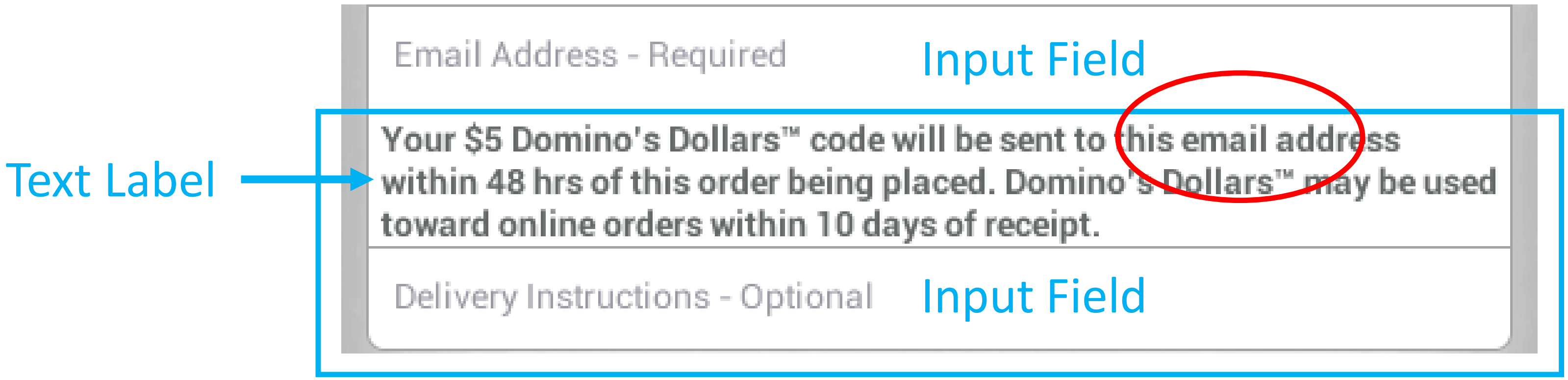

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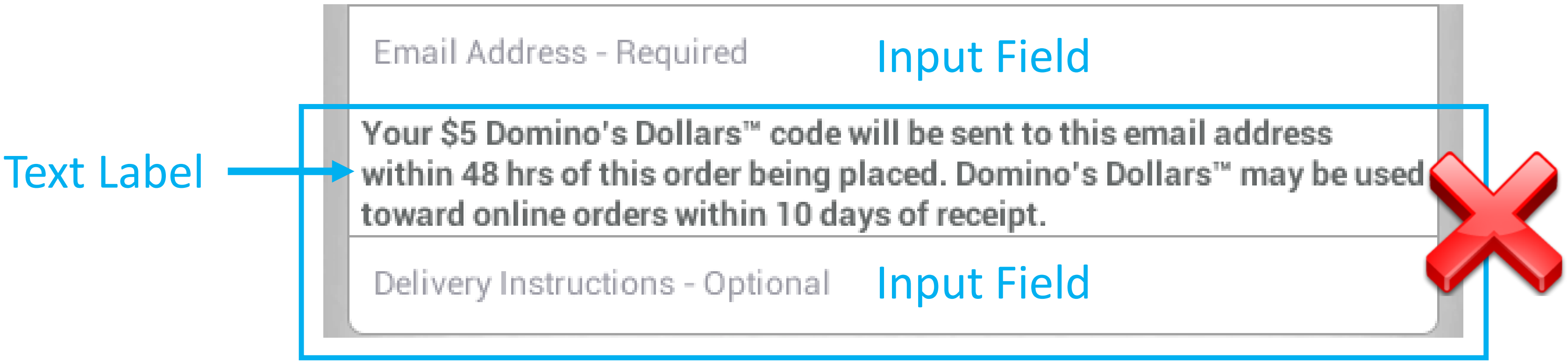

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Evaluating Disclosure Analysis

- For all 16,000 apps
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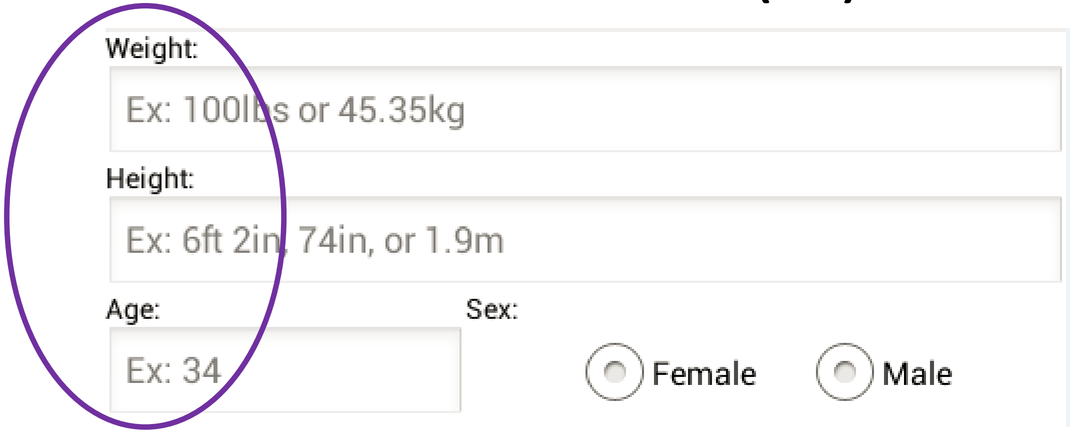
    - 3 apps are analyzed on each server in parallel

Evaluating Disclosure Analysis

- For all 16,000 apps
  - Throughput: **11.1** apps/minute
    - A cluster of 8 servers
    - 3 apps are analyzed on each server in parallel
  - Manually examined 104 apps
  - False positive rate is **8.7%**
    - Limitations of underlying taint analysis framework
      - E.g. lack of accurate modeling of arrays

Case Studies (1)



Weight:

Ex: 100lbs or 45.35kg

Height:

Ex: 6ft 2in, 74in, or 1.9m

Age:

Ex: 34

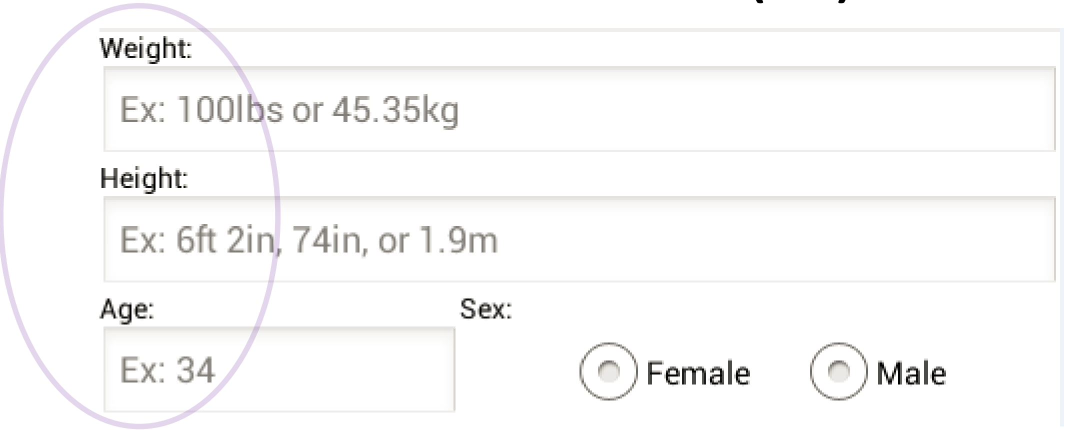
Sex:

○ Female ○ Male

com.canofsleep.wwdiary

3 input fields associated with labels “Weight”, “Height” and “Age” are identified sensitive.

Case Studies (1)



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com.canofsleep.wwdiary

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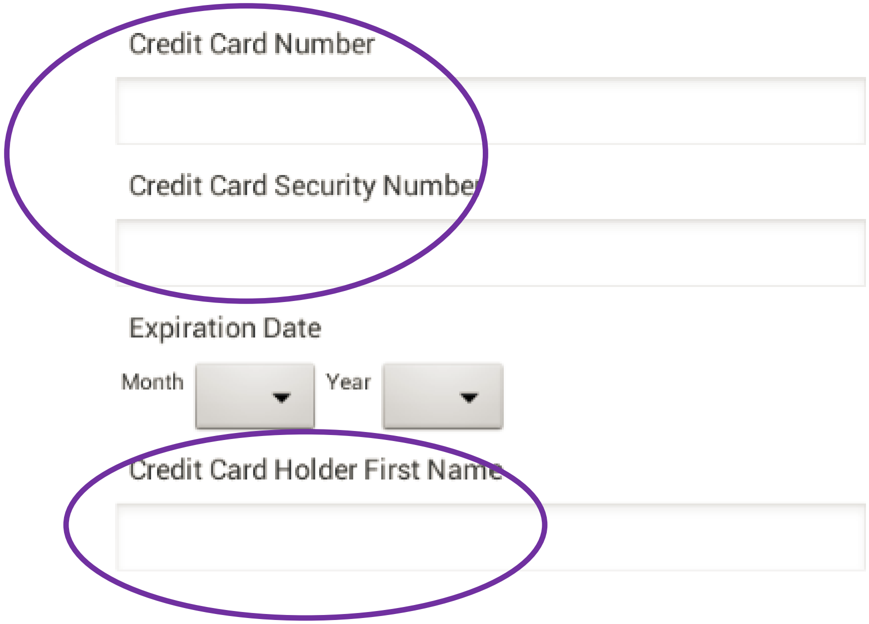


Credit Card Number

Credit Card Security Number

Expiration Date

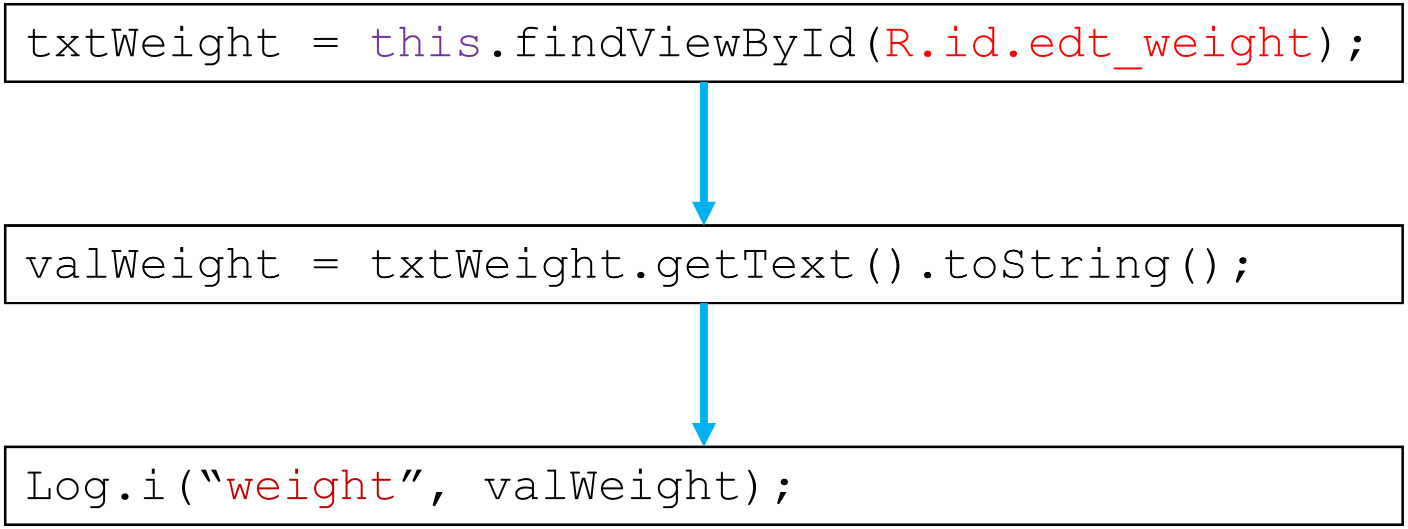
Month Year

Credit Card Holder First Name

com.nitrogen.android

The 3 marked inputs fields are identified sensitive and their data are disclosed.

Case Studies (2)



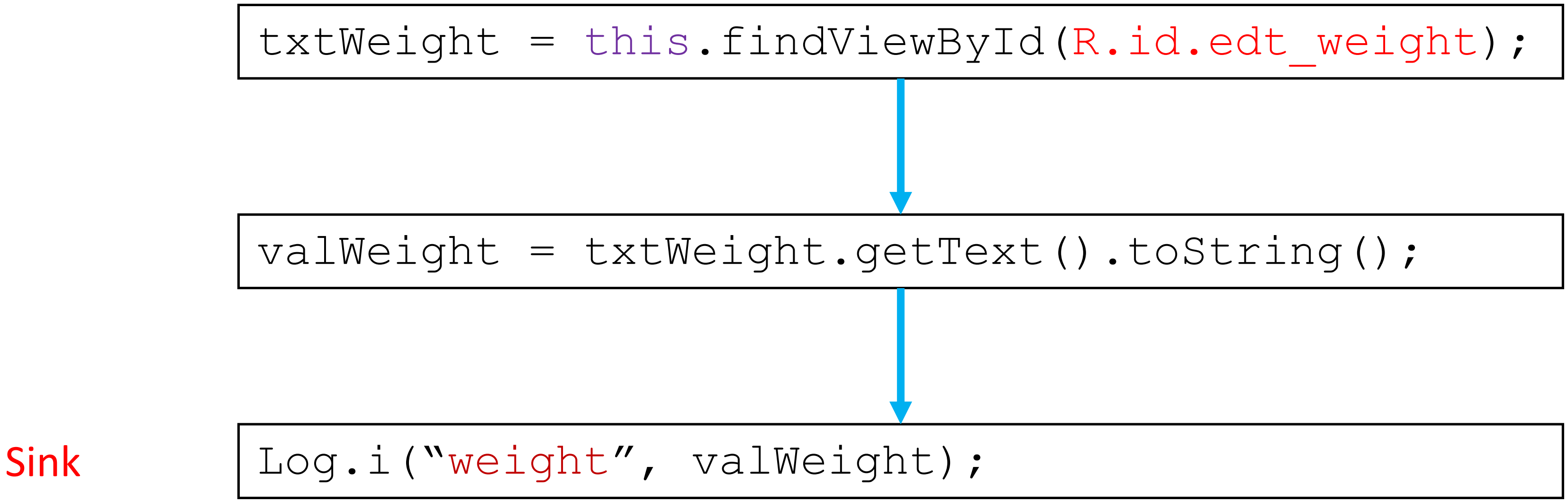
```
txtWeight = this.findViewById(R.id.edt_weight);
```

```
valWeight = txtWeight.getText().toString();
```

```
Log.i(“weight”, valWeight);
```

Case Studies (2)

- Disclosure analysis based on existing approach which directly define certain APIs as sensitive sources.



```
txtWeight = this.findViewById(R.id.edt_weight);
```

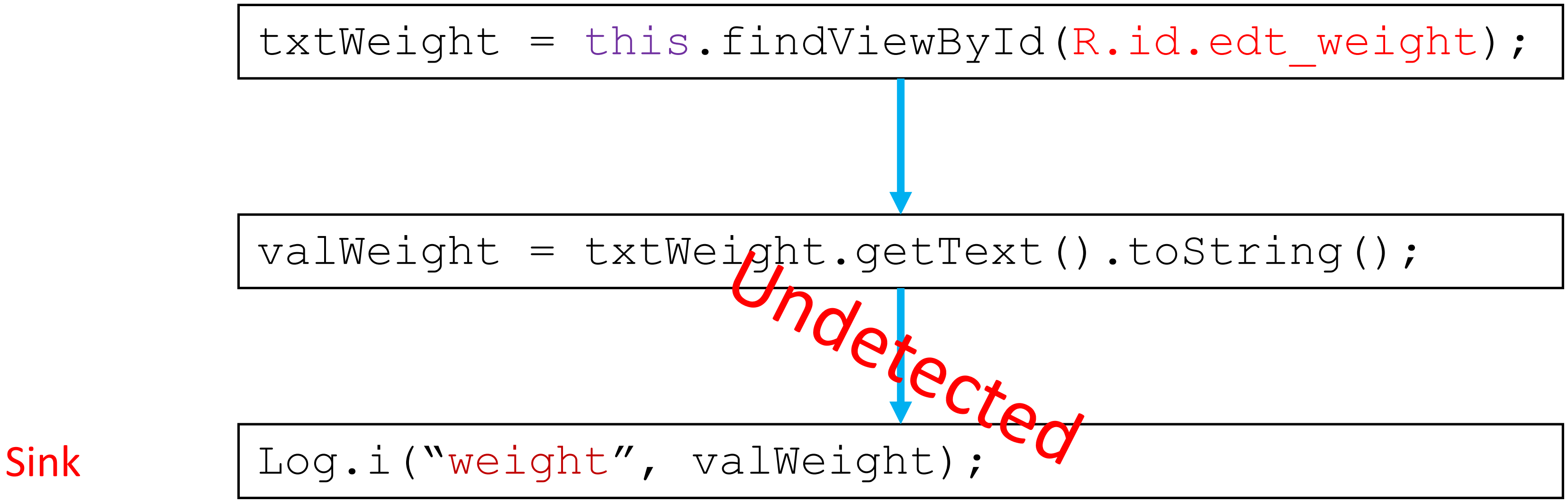
```
valWeight = txtWeight.getText().toString();
```

Sink

```
Log.i("weight", valWeight);
```

Case Studies (2)

- Disclosure analysis based on existing approach which directly define certain APIs as sensitive sources.



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```

```
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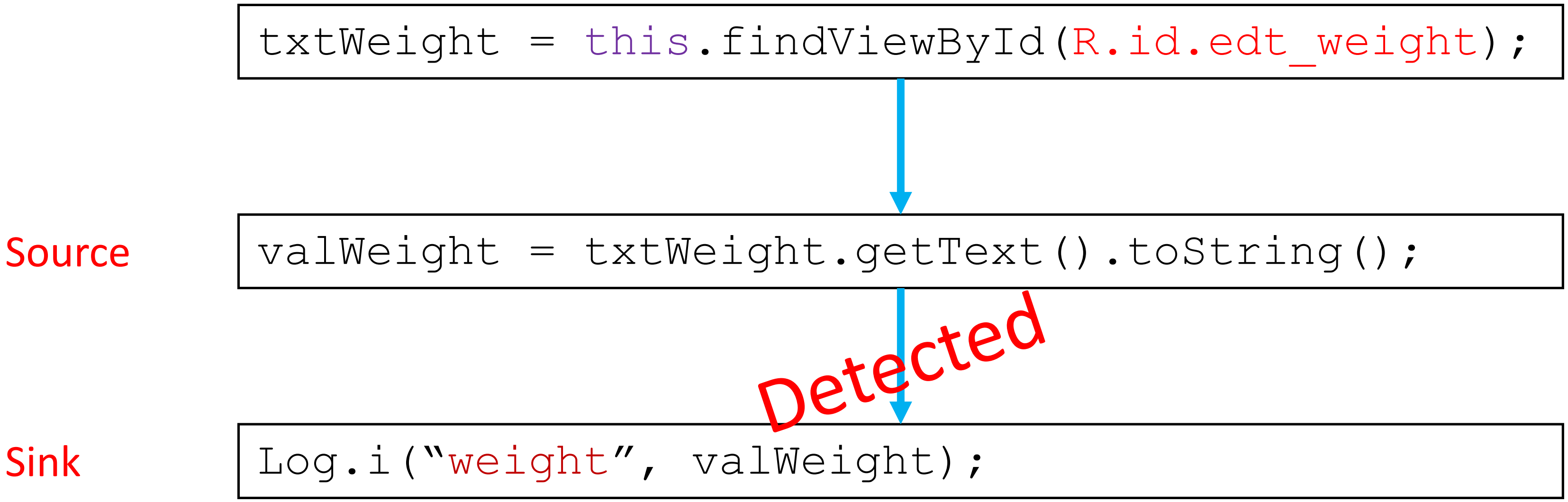
Case Studies (2)

- Disclosure analysis based on SUPOR



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Conclusion

- We study the possibility of detecting sensitive user inputs, an important yet mostly neglected sensitive source in mobile apps.

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- We propose SUPOR, among the *first* known approaches to detect sensitive user inputs with high recall and precision.
  - Mimics from the user's perspective by statically and scalably rendering the layout files.
  - Leverages a geometry-based approach to precisely associated text labels to input fields.
  - Utilizes textual analysis to determine the sensitiveness of the texts in labels.

Conclusion

- We study the possibility of detecting sensitive user inputs, an important yet mostly neglected sensitive source in mobile apps.
- We propose SUPOR, among the *first* known approaches to detect sensitive user inputs with high recall and precision.
  - Mimics from the user's perspective by statically and scalably rendering the layout files.
  - Leverages a geometry-based approach to precisely associated text labels to input fields.
  - Utilizes textual analysis to determine the sensitiveness of the texts in labels.
- We perform a sensitive user inputs disclosure analysis, with FP rate of 8.7%, to demonstrate the usefulness of SUPOR.

Thank You!

Q & A

PURDUE UNIVERSITY

NEC Laboratories America
Relentless passion for innovation

Georgia Tech

Related work

- A lot of work focus on privacy disclosure problems on predefined sensitive data sources in the phone.[FlowDroid PLDI’14, PiOS NDSS’11, AAPL NDSS’15]
- FlowDroid employs a limited form of sensitive input fields—password fields.[PLDI’14]
- AsDroid checks checks UI text to detect the contradiction between the expected behaviors and program behaviors.[ICSE’14]
- UIPicker uses supervised learning to collect sensitive keywords and corresponding layouts. It also uses the sibling elements in layout files as the description text for a widget.[USENIX Security’15]

Keyword dataset construction

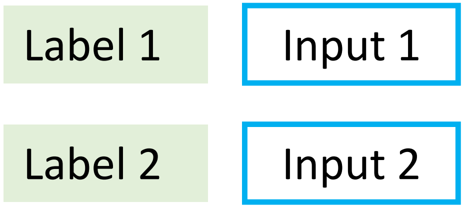
- Crawl texts from apps' resource files
- Adapt NLP techniques to extract nouns and noun phrases from the top 5,000 frequent text lines.
- Manually inspect top frequent nouns and noun phrases to identify sensitive keywords.

Why not use XML structure to compute correlation scores?

- Many developers defines relative positions of the widgets, which are not what users perceive
  - XML structure in this case does not guarantee that sibling widgets are physically close.

Why not use XML structure to compute correlation scores?

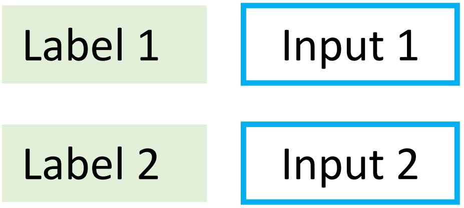
- Some cases in real Android apps.



Why not use XML structure to compute correlation scores?

- Some cases in real Android apps.

```
<LinearLayout android:orientation=“horizontal”>
  <LinearLayout android:orientation=“vertical”>
    <TextView android:text=“Label 1‟ />
    <TextView android:text=“Label 2‟ />
  </LinearLayout>
  <LinearLayout android:orientation=“vertical”>
    <EditText android:id=“@+id/input1‟ … />
    <EditText android:id=“@+id/input2‟ … />
  </LinearLayout>
</LinearLayout>
```



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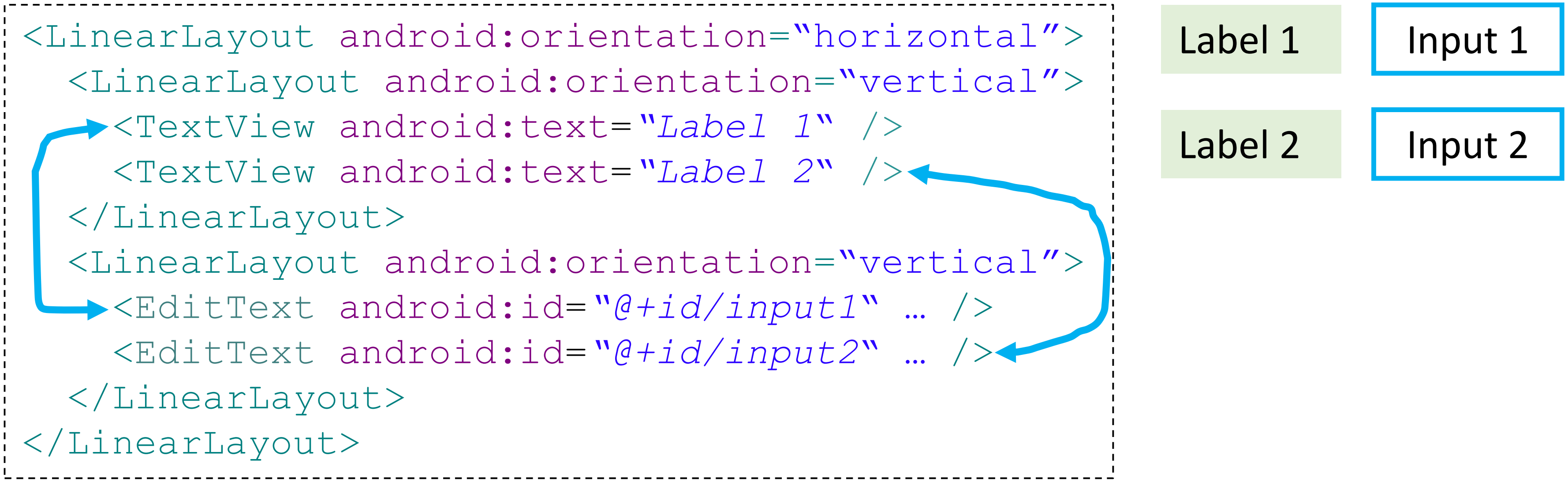

```
<LinearLayout android:orientation=“horizontal”>
  <LinearLayout android:orientation=“vertical”>
    <TextView android:text=“Label 1“ />
    <TextView android:text=“Label 2“ />
  </LinearLayout>
  <LinearLayout android:orientation=“vertical”>
    <EditText android:id=“@+id/input1“ … />
    <EditText android:id=“@+id/input2“ … />
  </LinearLayout>
</LinearLayout>
```