Automated API-Usage Update for Android Apps

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Georgia Tech College of Computing

Mobile Applications





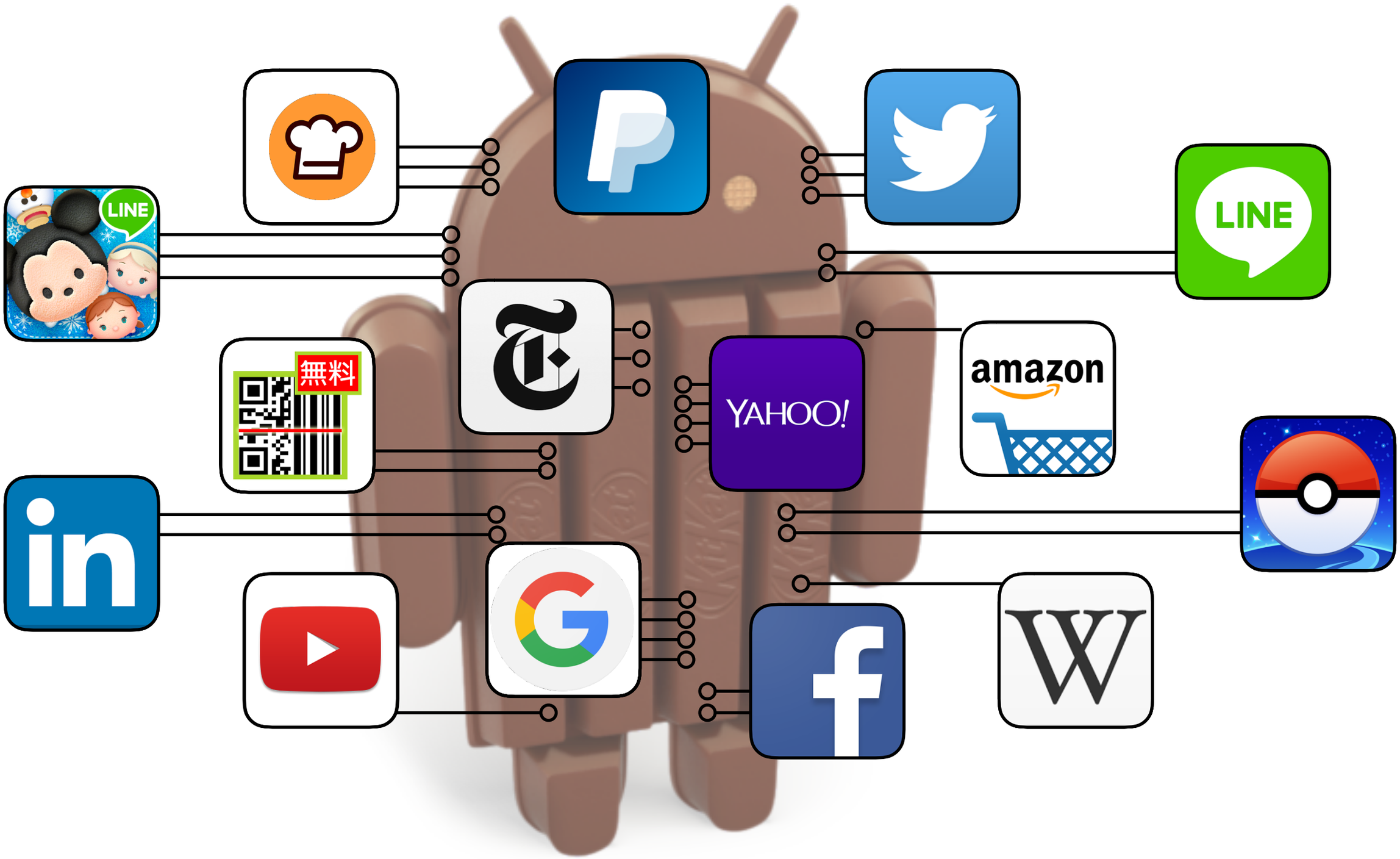




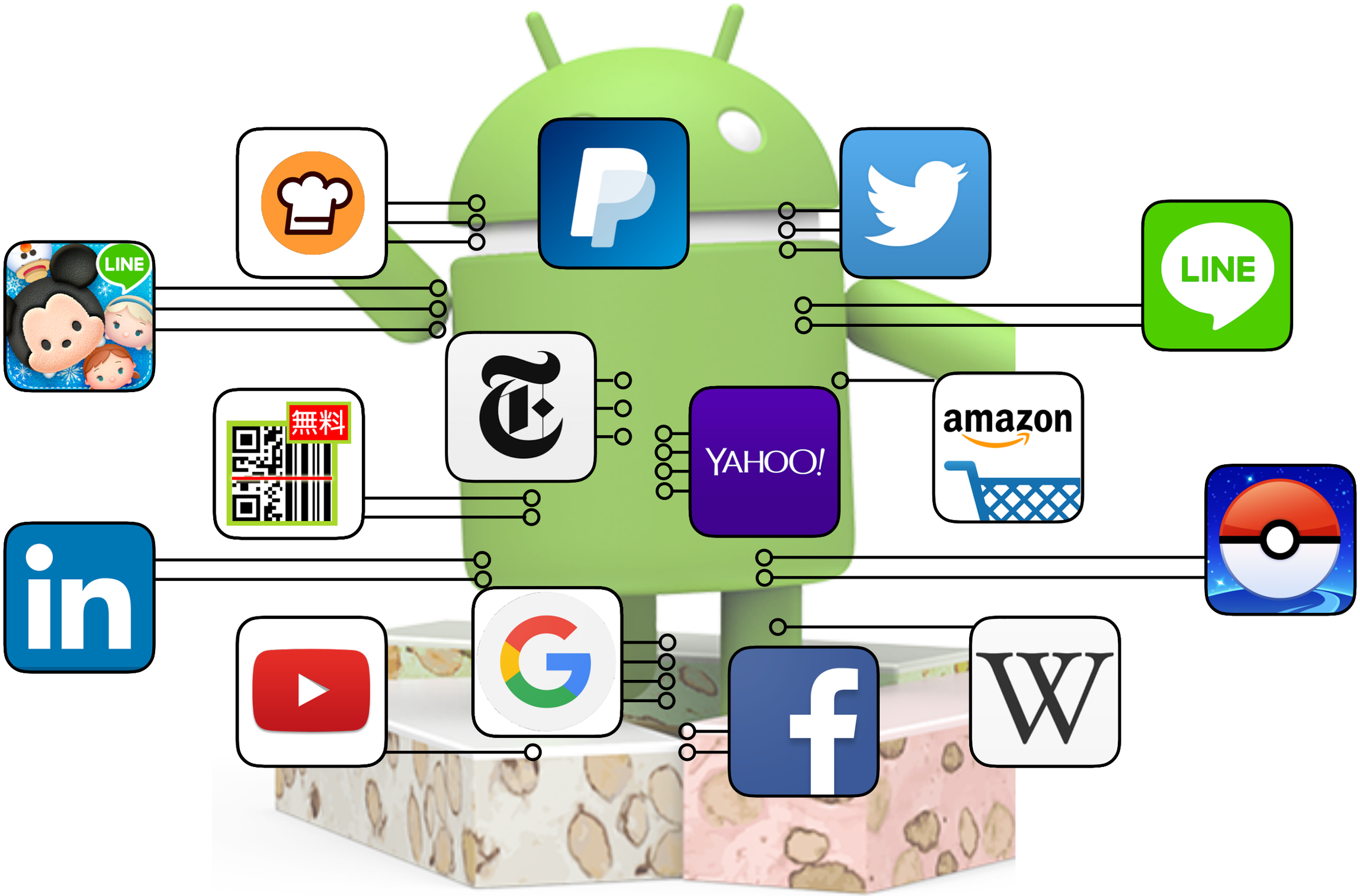

Platform

Platform

Tight Coupling



Platforms Change



Platforms Change Frequently

Android

Petit Four

Cupcake

Donut

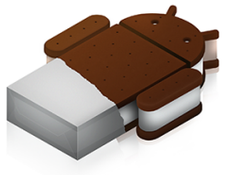
Eclair

Froyo

Gingerbread

Honeycomb

Ice Cream



Jelly Bean

KitKat

Lollipop

Marshmallow

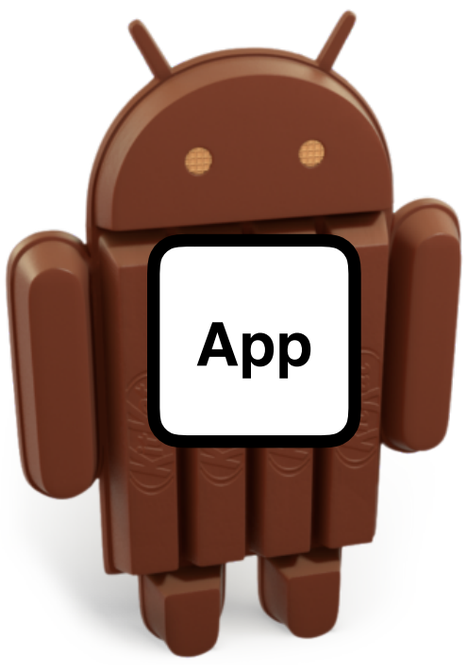
Nougat

Oreo

Pie

Adaptive Maintenance

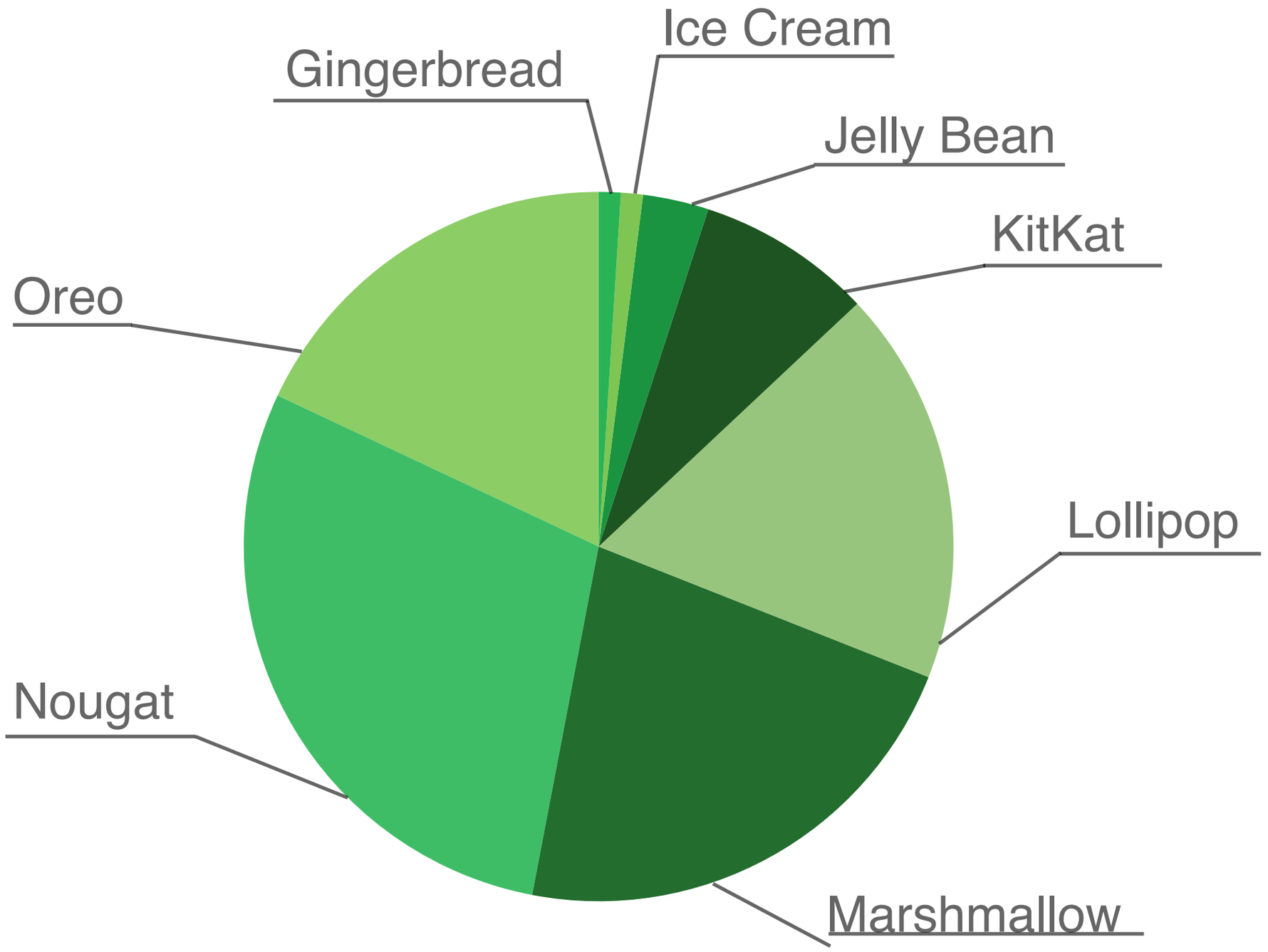
Platform



Developer

New Platform

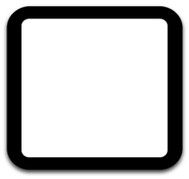
Platform Fragmentation



Intuition

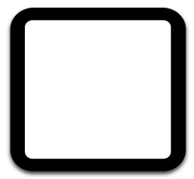
Developer A

App A



Developer B

App B



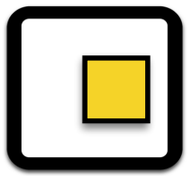
Developer C

App C

Intuition

Developer A

App A



Developer B

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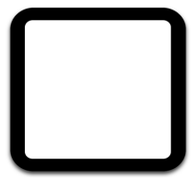

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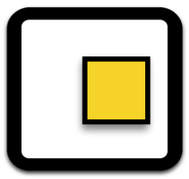

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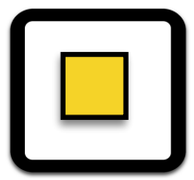

Developer C

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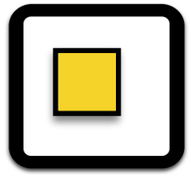

API Updates

API-Usage Changes

```
public NetworkInfo[] getAllNetworkInfo()
```

This method was deprecated in API level 23.

This method does not support multiple connected networks of the same type.

Use **`getAllNetworks()`** and **`getNetworkInfo(android.net.Network)`** instead.

Old API Usage

```
public NetworkInfo[] getAllNetworkInfo()
```

New API Usage

```
public Network[] getAllNetworks()
public NetworkInfo getNetworkInfo(Network network)
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API Updates

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Update Example

Update Example Before

```
public boolean isConnected(Context cont) {
  ConnectivityManager cm = ...;
  NetworkInfo[] info = cm.getAllNetworkInfo();
  for (int i = 0; i < info.length; i++) {
    if(info[i].isConnected()) {
      return true;
    } }
  Toast.makeText(R.s.noNet).show();
  return false;
}
```

Update Example After

```
public boolean isConnected(Context cont) {
  ConnectivityManager cm = ... ;
  if (VERSION.SDK_INT >= VERSION_CODES.M) {
    Network[] networks = cm.getAllNetworks();
    for (Network mNetwork : networks) {
      NetworkInfo networkInfo =
        cm.getNetworkInfo(mNetwork);
      if(networkInfo.isConnected()) {
        Log.d(networkInfo.getTypeName());
        return true;
      } }
  } else {
    NetworkInfo[] info = cm.getAllNetworkInfo();
    for (NetworkInfo anInfo : info) {
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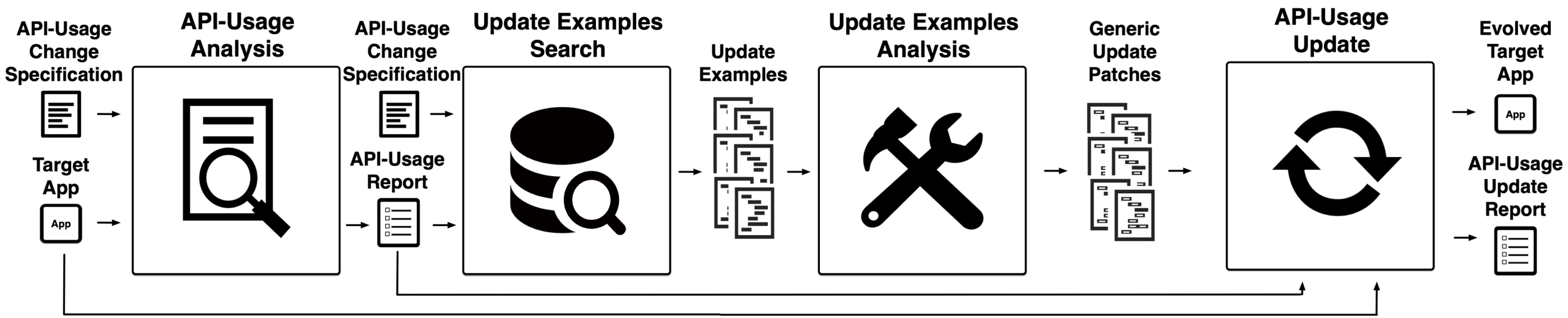
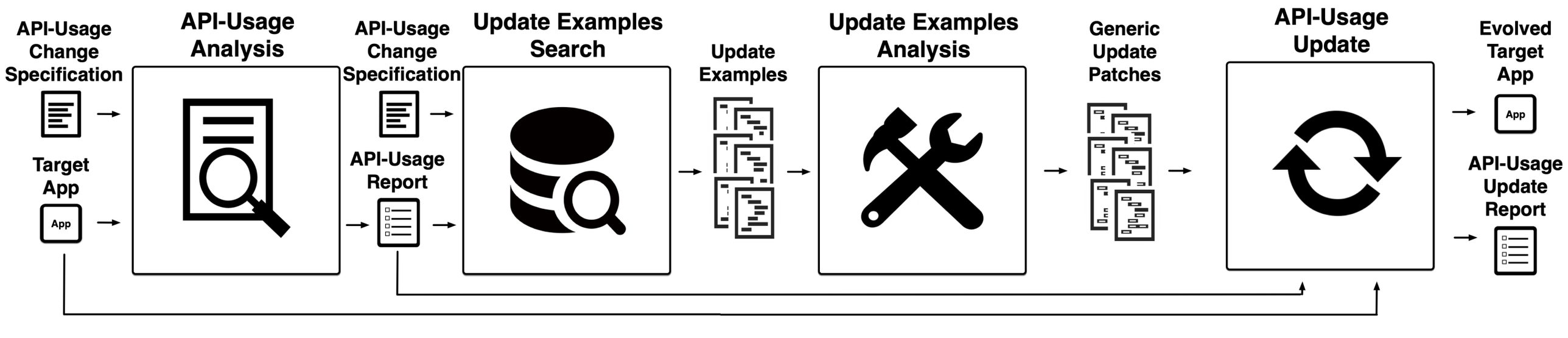
AppEvolve Overview



1. Identify API usages requiring update in target app
2. Find update examples for identified API usages
3. Abstract update examples into generic update patches and rank them
4. Update and validate API usages in target app based on patches

APPEVOLVE Overview



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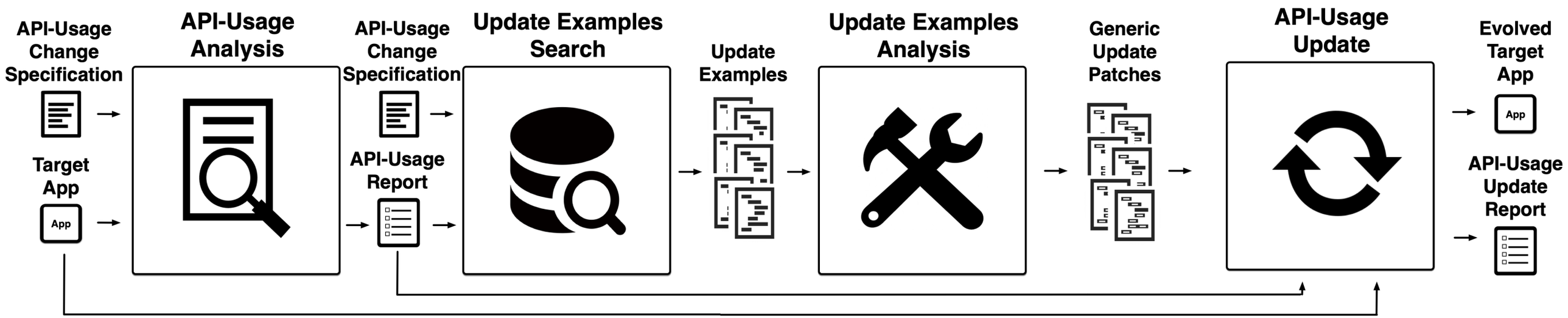

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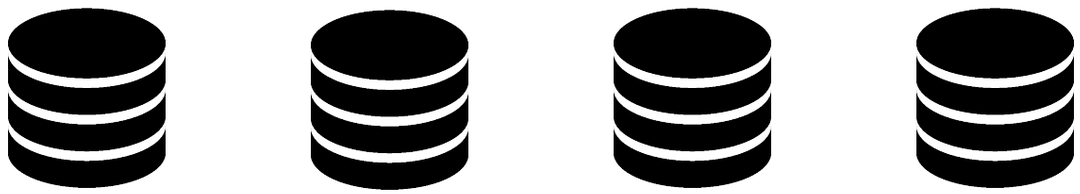
Update Example Search

2

Code Hosting Infrastructure



Keyword-Based Search

$\forall$ method signature $\in$ **New API Usage**

method name, param types, declaring class

Search Result

Code Base App$_1$

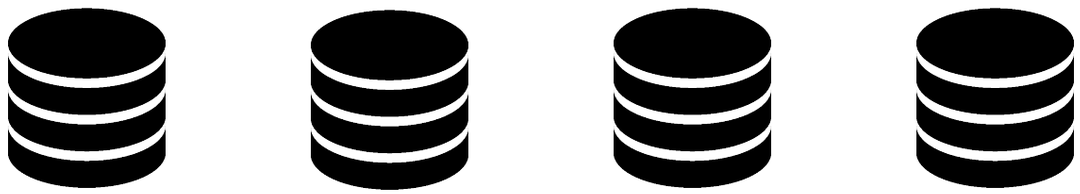
Code Base App$_2$

Code Base App$_3$

Code Base App$_4$

Update Example Search

Code Hosting Infrastructure



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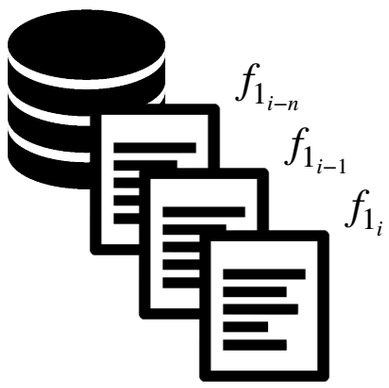
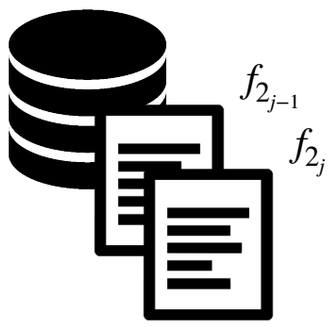
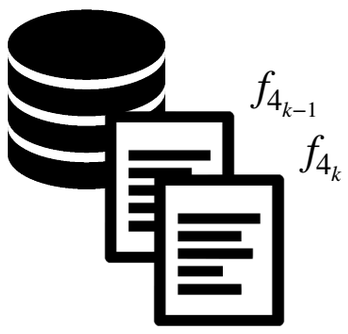


Code Base App$_2$



Code Base App$_3$

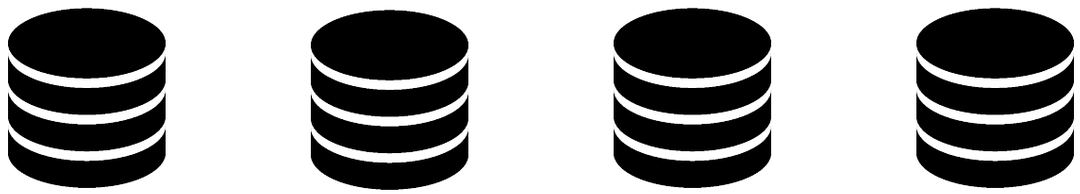
Code Base App$_4$



Update Example Search

2

Code Hosting Infrastructure



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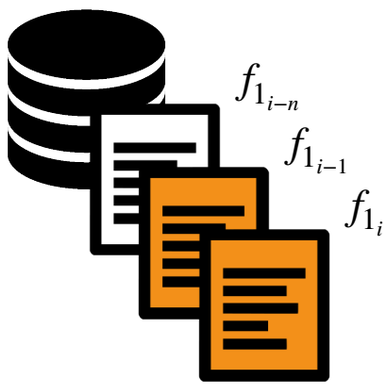

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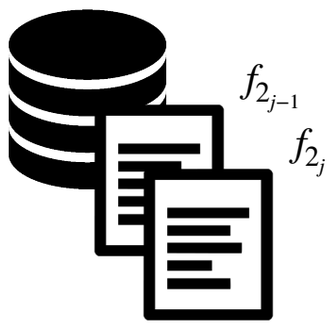

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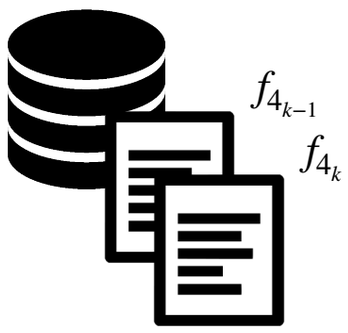

Update Example Search

2

Before Update $(f_{1_{i-1}})$

```
public boolean isConnected(Context cont) {
  ConnectivityManager cm = ...;
  NetworkInfo[] info = cm.getAllNetworkInfo();
  for (int i = 0; i < info.length; i++) {
    if(info[i].isConnected()) {
      return true;
    } }
  Toast.makeText(R.s.noNet).show();
  return false;
}
```

After Update (f_{1_i})

```
public boolean isConnected(Context cont) {
  ConnectivityManager cm = ... ;
  if (VERSION.SDK_INT >= VERSION_CODES.M) {
    Network[] networks = cm.getAllNetworks();
    for (Network mNetwork : networks) {
      NetworkInfo networkInfo =
        cm.getNetworkInfo(mNetwork);
      if(networkInfo.isConnected()) {
        Log.d(networkInfo.getTypeName());
        return true;
      } }
  } else {
    NetworkInfo[] info = cm.getAllNetworkInfo();
    for (NetworkInfo anInfo : info) {
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```

Update Example Search

2

Compute Differences

Before Update ($f_{1_{i-1}}$)

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Update Example Search

2

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+        return true;
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Added check on platform version

Added new API Usage

Moved old API Usage

Update Example Search

2

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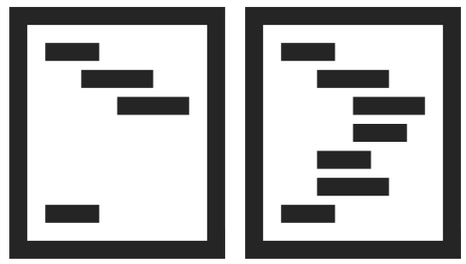
Update Example



Update Example Search

2

Compute Differences

Before Update $(f_{1_{i-1}})$

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   Connect
-  Network
-  for (ir
-
-
```

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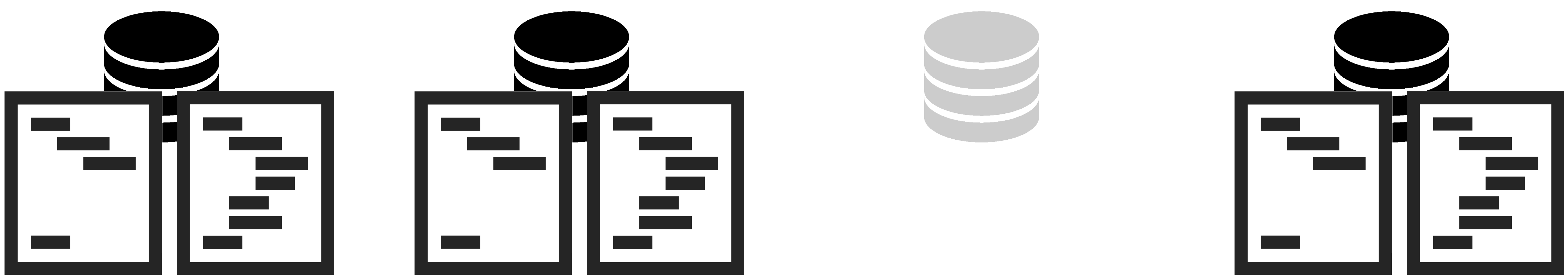
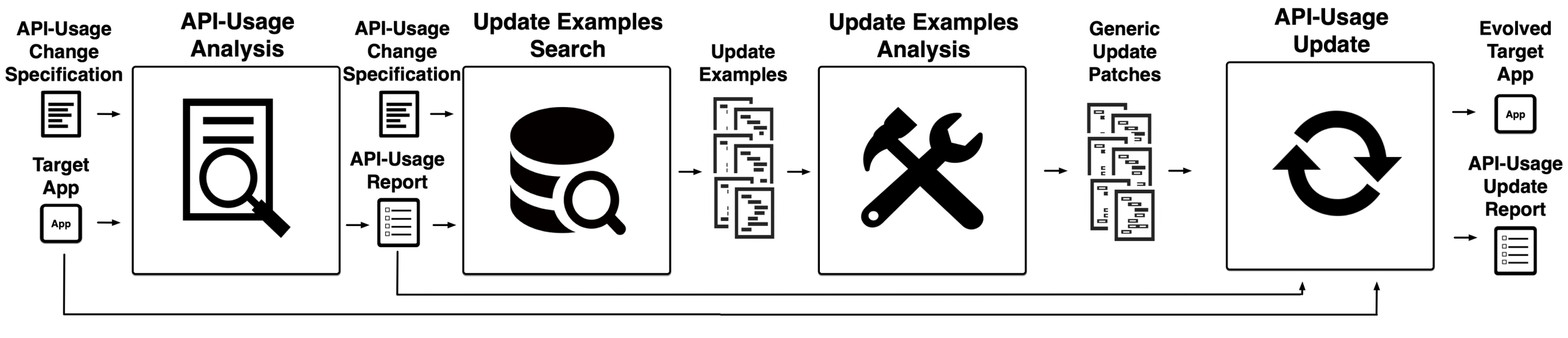
Update Examples

Code Base App₁ **Code Base App₂** Code Base App₃ **Code Base App₄**



APPEVOLVE Overview



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Update Example Analysis

3

Compute Update Patch

Update Example Before ($f_{1_{i-1}}$)

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  ConnectivityManager cm = ...;
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  for (int i = 0; i < info.length; i++) {
    if(info[i].isConnected()) {
      return true;
    } }
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Update Example After (f_{1_i})

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public boolean isConnected(Context cont) {
  ConnectivityManager cm = ... ;
  if (VERSION.SDK_INT >= VERSION_CODES.M) {
    Network[] networks = cm.getAllNetworks();
    for (Network mNetwork : networks) {
      NetworkInfo networkInfo =
        cm.getNetworkInfo(mNetwork);
      if(networkInfo.isConnected()) {
        Log.d(networkInfo.getTypeName());
        return true;
      } }
  } else {
    NetworkInfo[] info = cm.getAllNetworkInfo();
    for (NetworkInfo anInfo : info) {
      if(anInfo.isConnected()) {
        Log.d(anInfo.getTypeName());
        return true;
      } }
  }
  Toast.makeText(cont.getString(...)).show();
  return false;
}
```
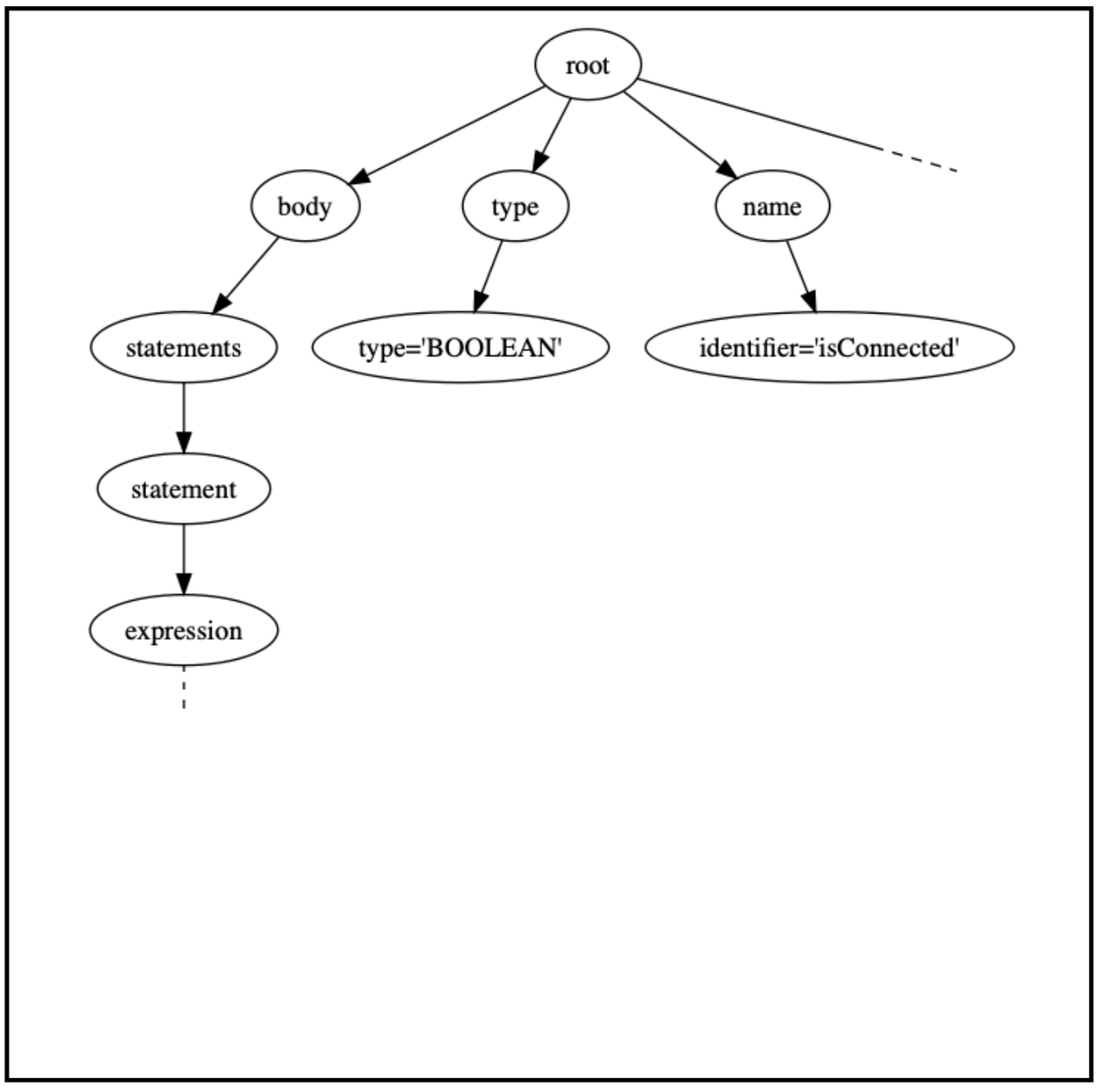

Update Example Analysis

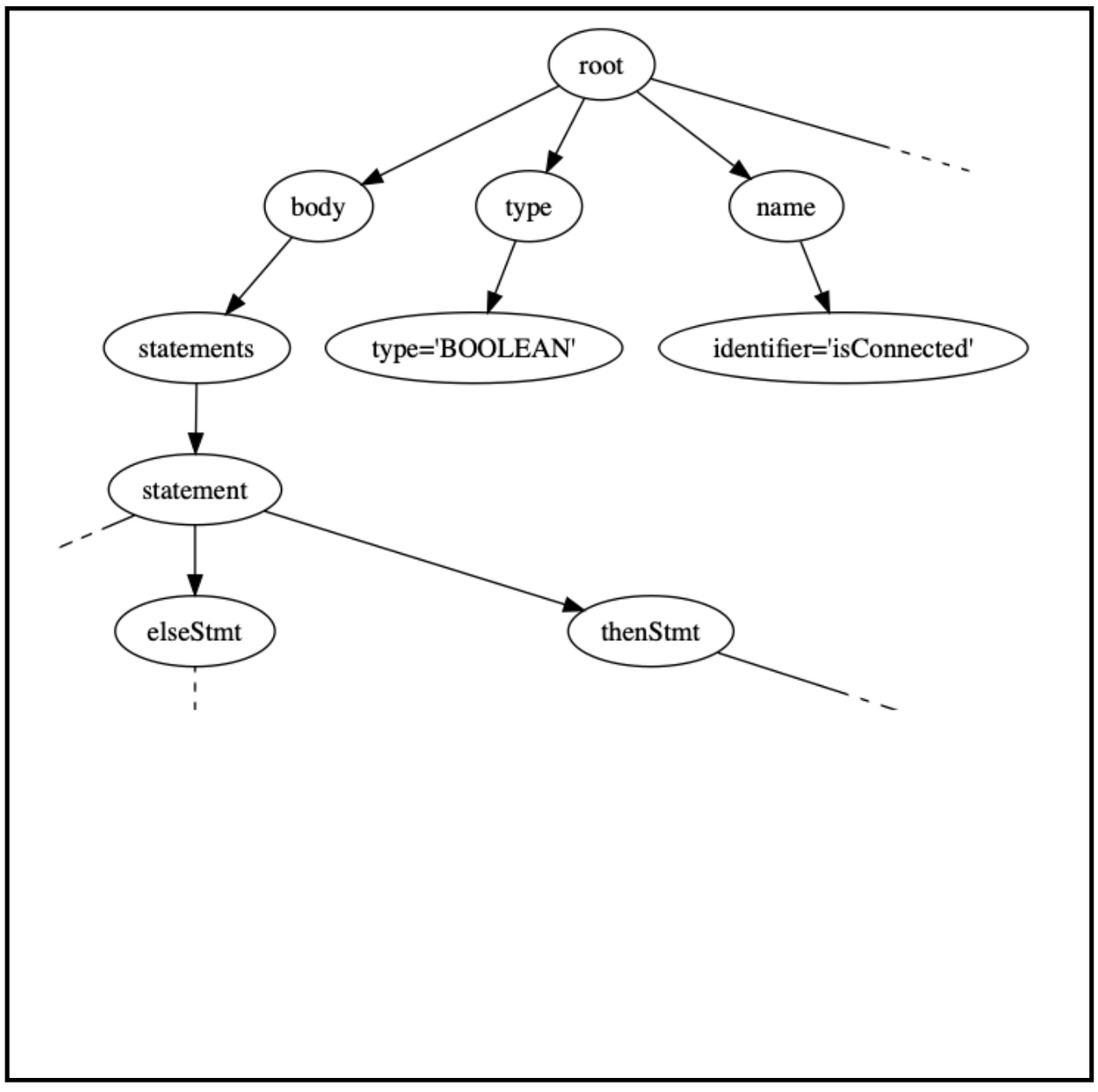
3

Compute Update Patch

Abstract Syntax Tree Before $(f_{1_{i-1}})$



Abstract Syntax Tree After (f_{1_i})

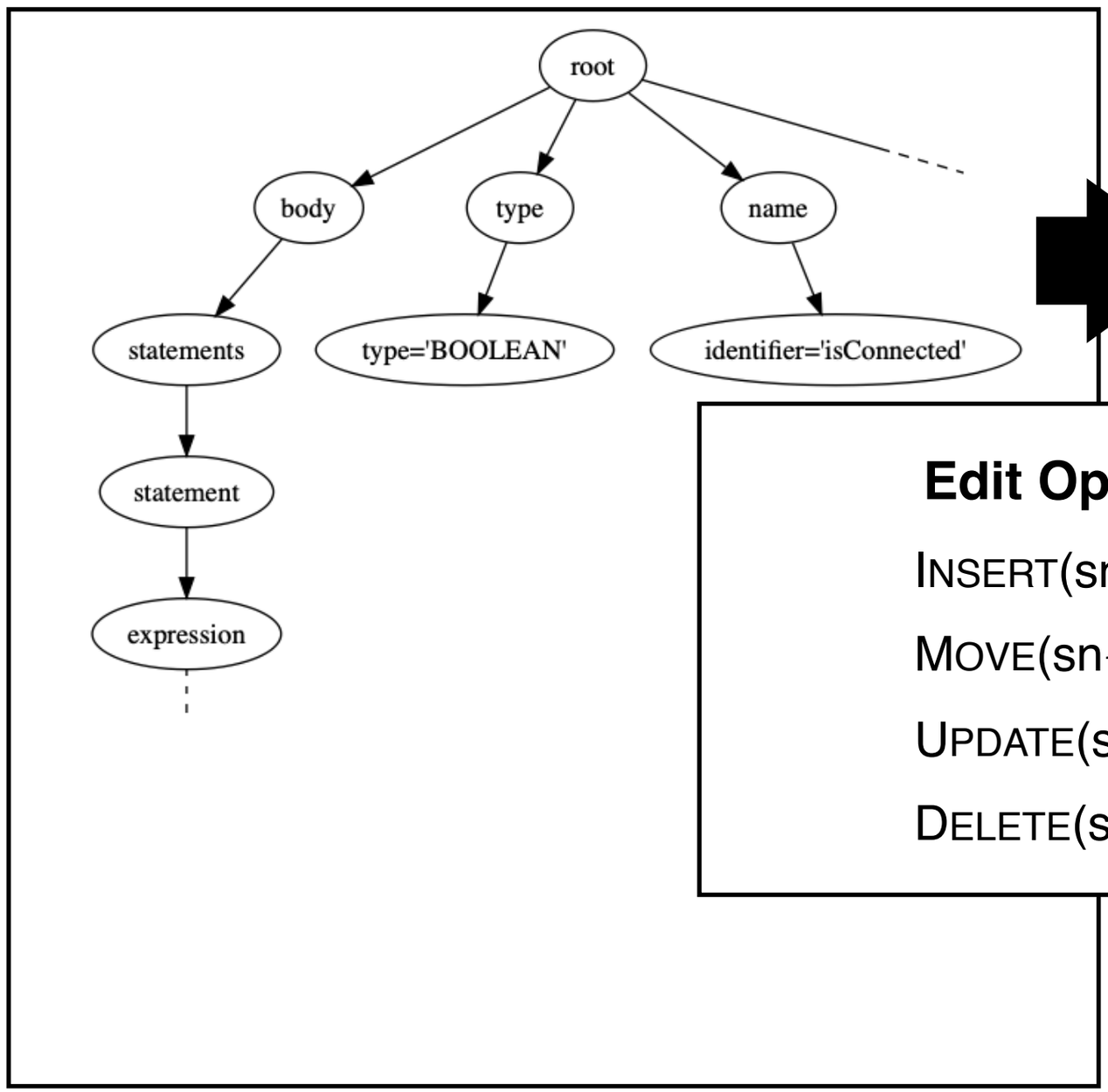


Update Example Analysis

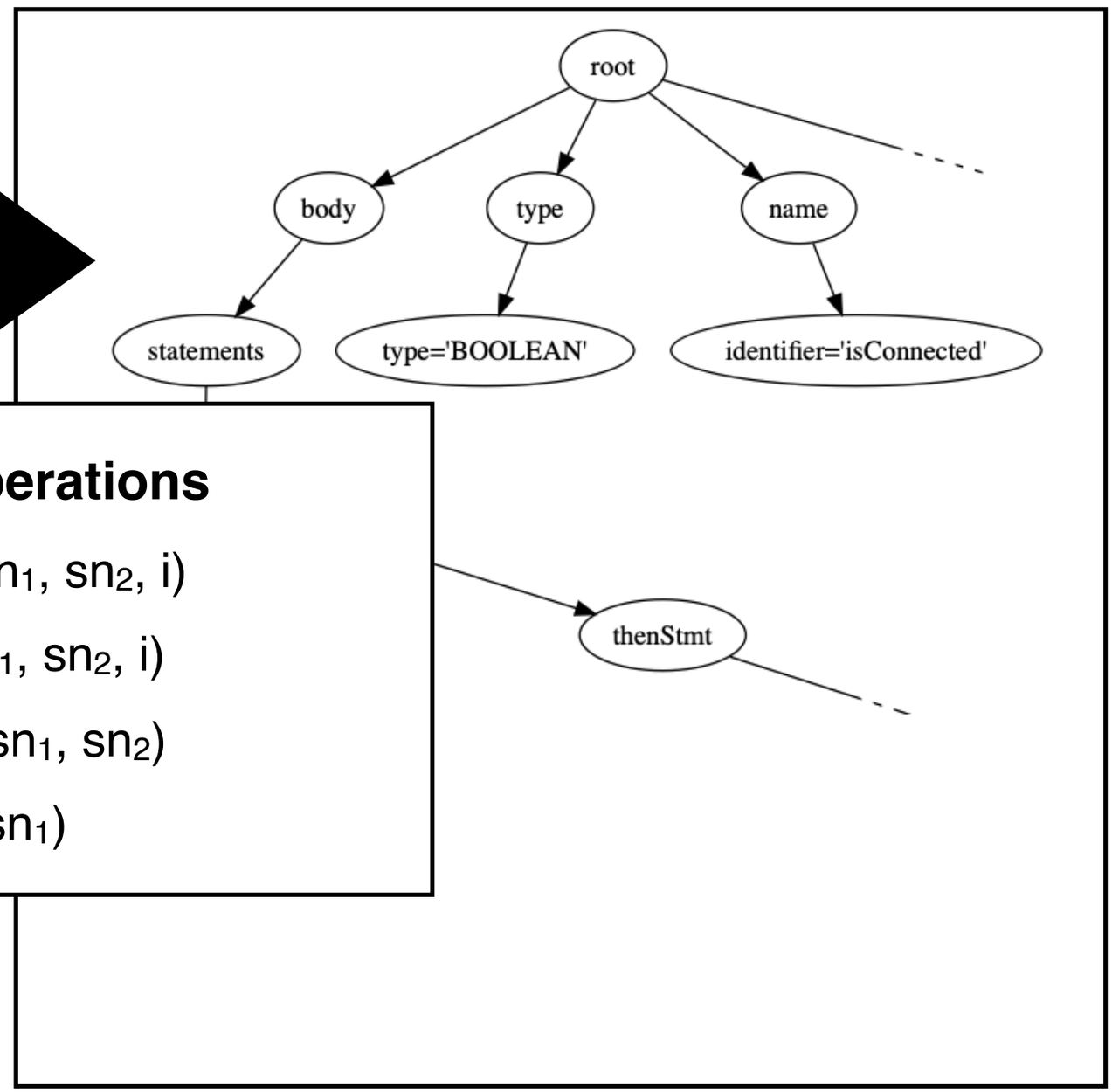
3

Compute Update Patch

Abstract Syntax Tree Before $(f_{1_{i-1}})$



Abstract Syntax Tree After (f_{1_i})



Edit Operations

INSERT(sn_1, sn_2, i)

MOVE(sn_1, sn_2, i)

UPDATE(sn_1, sn_2)

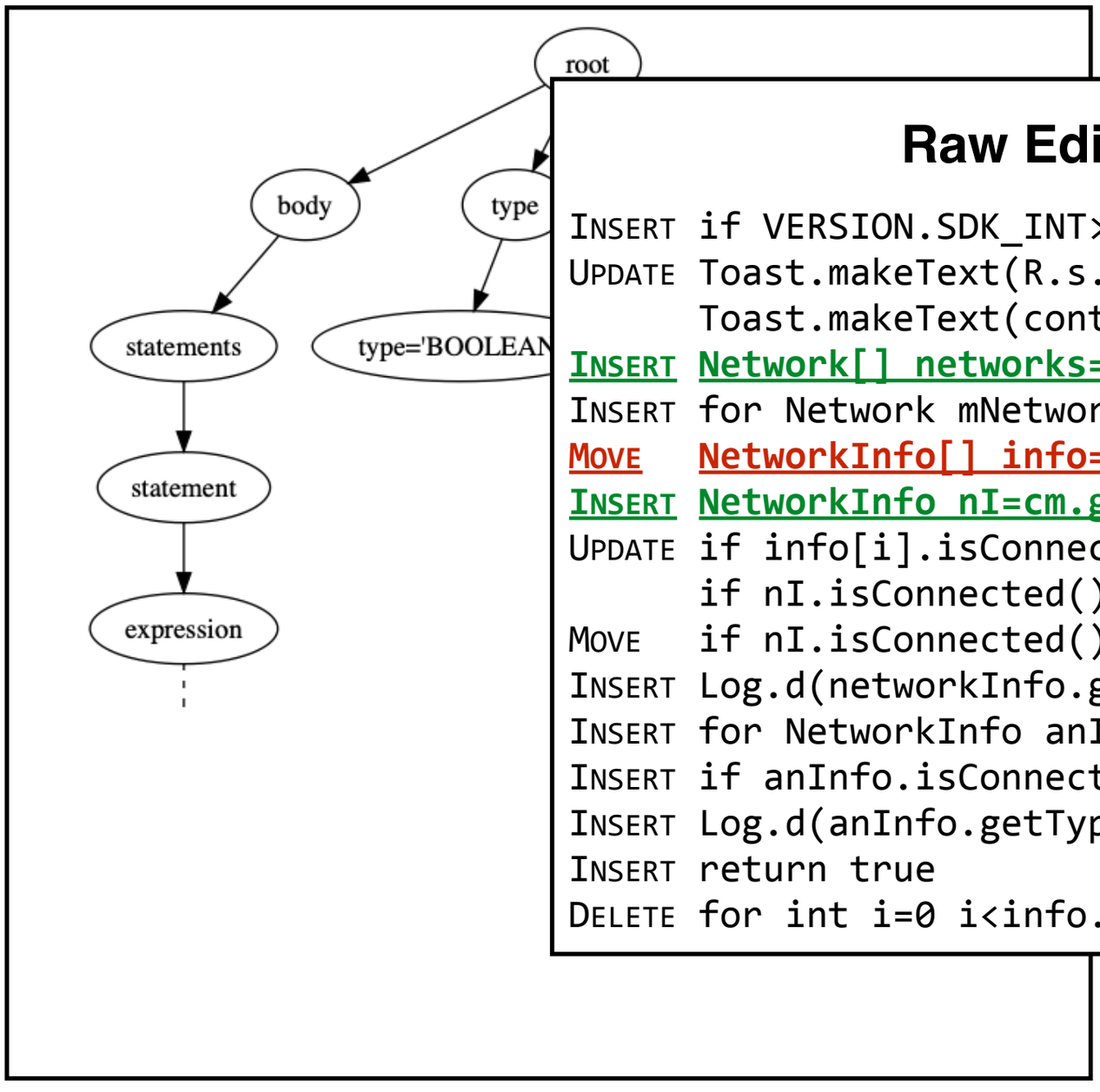
DELETE(sn_1)

Update Example Analysis

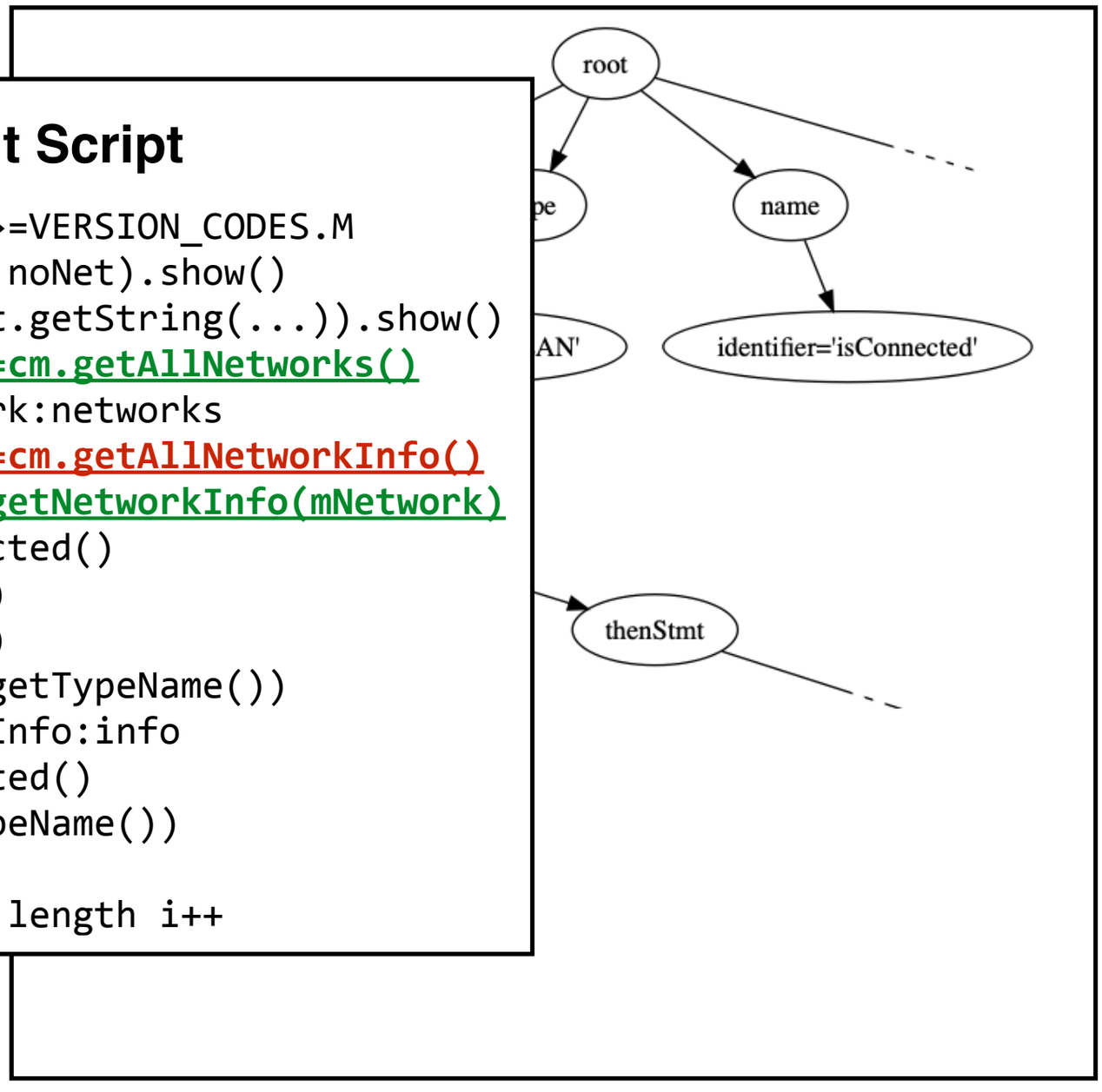
3

Compute Update Patch

Abstract Syntax Tree Before $(f_{1_{i-1}})$



Abstract Syntax Tree After (f_{1_i})



Raw Edit Script

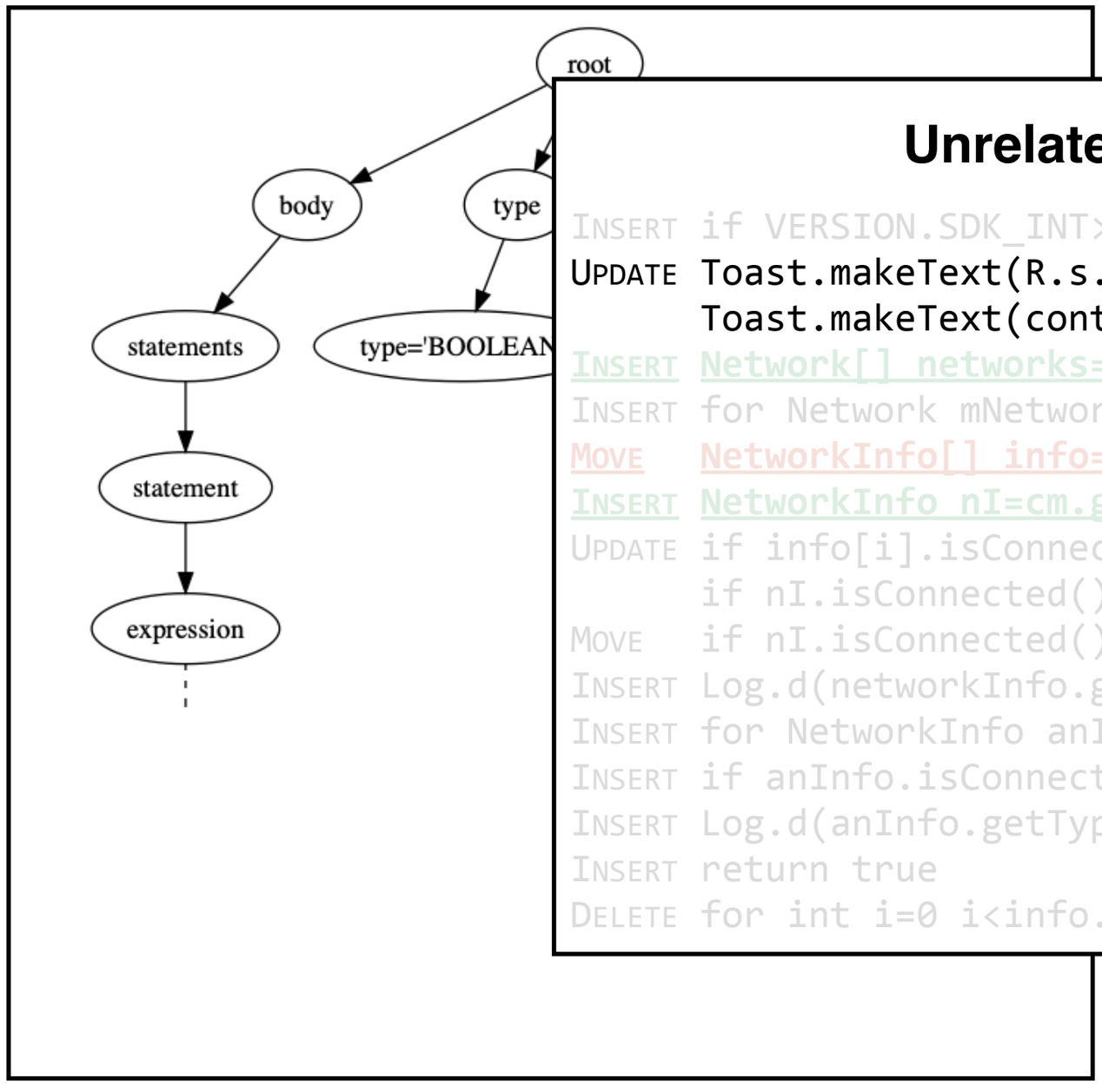
```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
UPDATE Toast.makeText(R.s.noNet).show()
       Toast.makeText(cont.getString(...)).show()
INSERT Network[] networks=cm.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=cm.getAllNetworkInfo()
INSERT NetworkInfo nI=cm.getNetworkInfo(mNetwork)
UPDATE if info[i].isConnected()
       if nI.isConnected()
MOVE   if nI.isConnected()
INSERT Log.d(networkInfo.getTypeName())
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.isConnected()
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Update Example Analysis

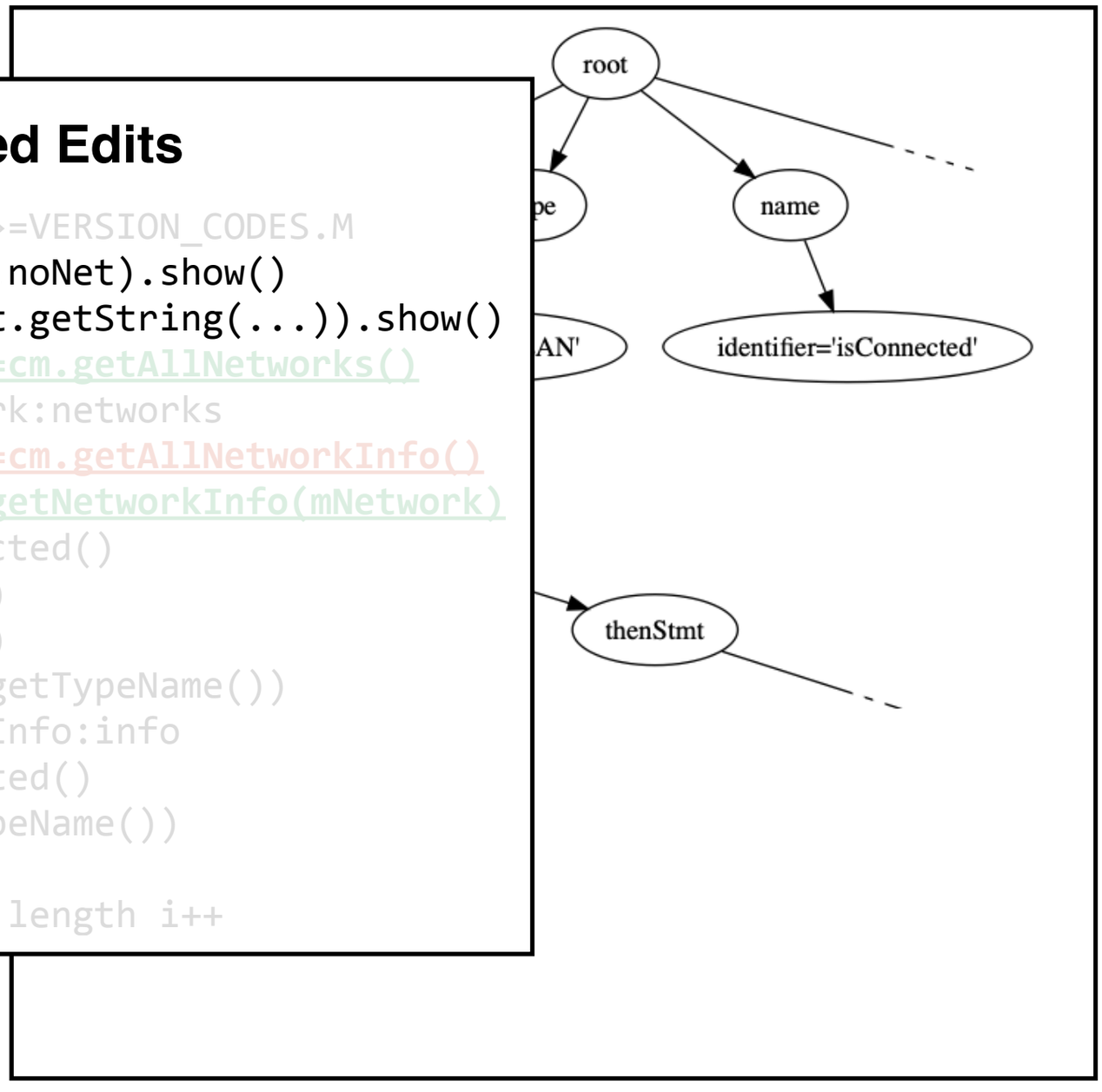
3

Compute Update Patch

Abstract Syntax Tree Before $(f_{1_{i-1}})$



Abstract Syntax Tree After (f_{1_i})



Unrelated Edits

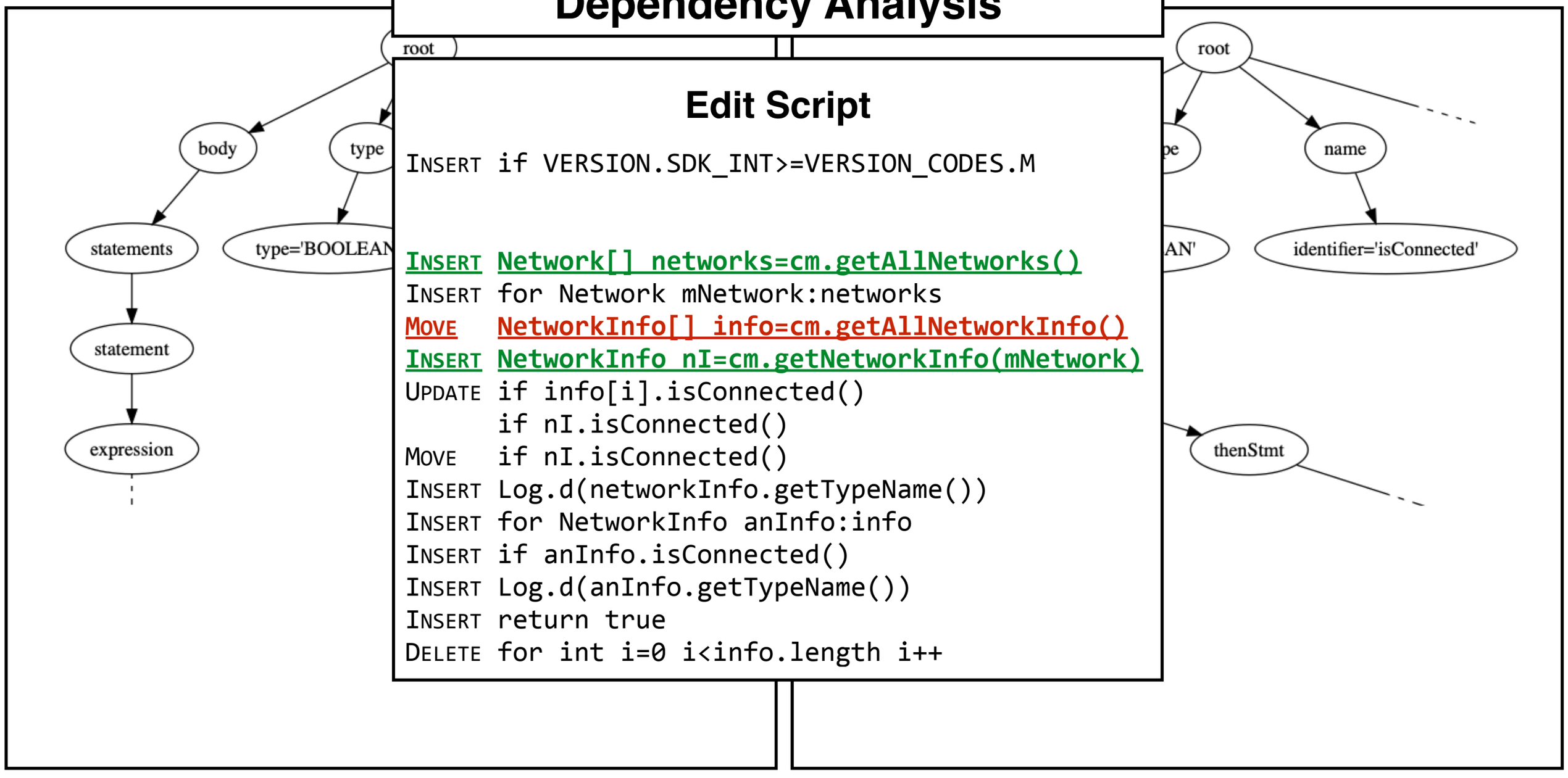
```
INSERT  if VERSION.SDK_INT>=VERSION_CODES.M
UPDATE  Toast.makeText(R.s.noNet).show()
        Toast.makeText(cont.getString(...)).show()
INSERT  Network[] networks=cm.getAllNetworks()
INSERT  for Network mNetwork:networks
MOVE    NetworkInfo[] info=cm.getAllNetworkInfo()
INSERT  NetworkInfo nI=cm.getNetworkInfo(mNetwork)
UPDATE  if info[i].isConnected()
        if nI.isConnected()
MOVE    if nI.isConnected()
INSERT  Log.d(networkInfo.getTypeName())
INSERT  for NetworkInfo anInfo:info
INSERT  if anInfo.isConnected()
INSERT  Log.d(anInfo.getTypeName())
INSERT  return true
DELETE  for int i=0 i<info.length i++
```

Update Example Analysis

3

Compute Update Patch

Abstract Syntax Tree Before (f_{1_i}) **Abstract Syntax Tree After** (f_{1_i})



Dependency Analysis

Edit Script

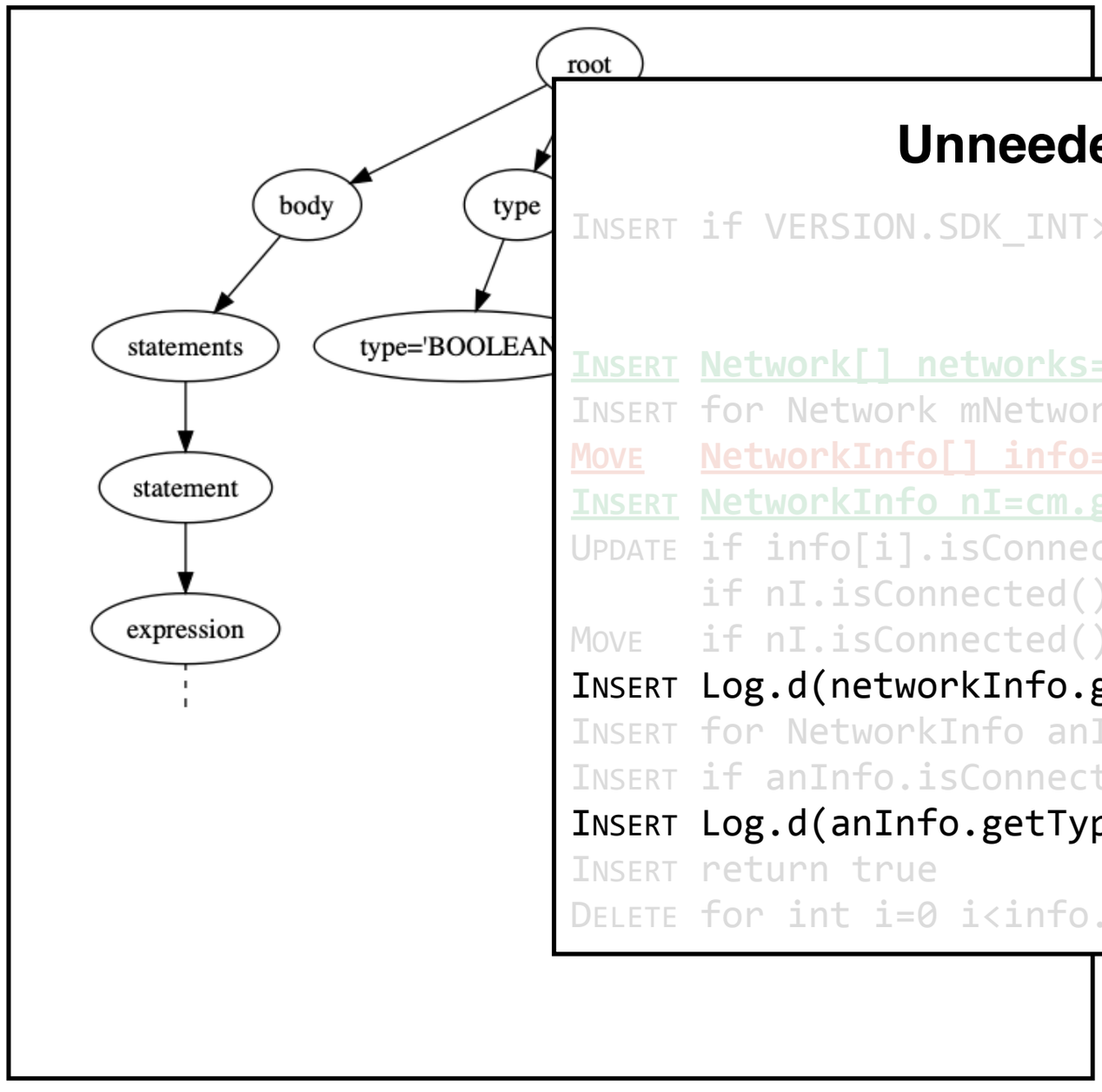
```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M

INSERT Network[] networks=cm.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=cm.getAllNetworkInfo()
INSERT NetworkInfo nI=cm.getNetworkInfo(mNetwork)
UPDATE if info[i].isConnected()
       if nI.isConnected()
MOVE   if nI.isConnected()
INSERT Log.d(networkInfo.getTypeName())
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.isConnected()
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Update Example Analysis

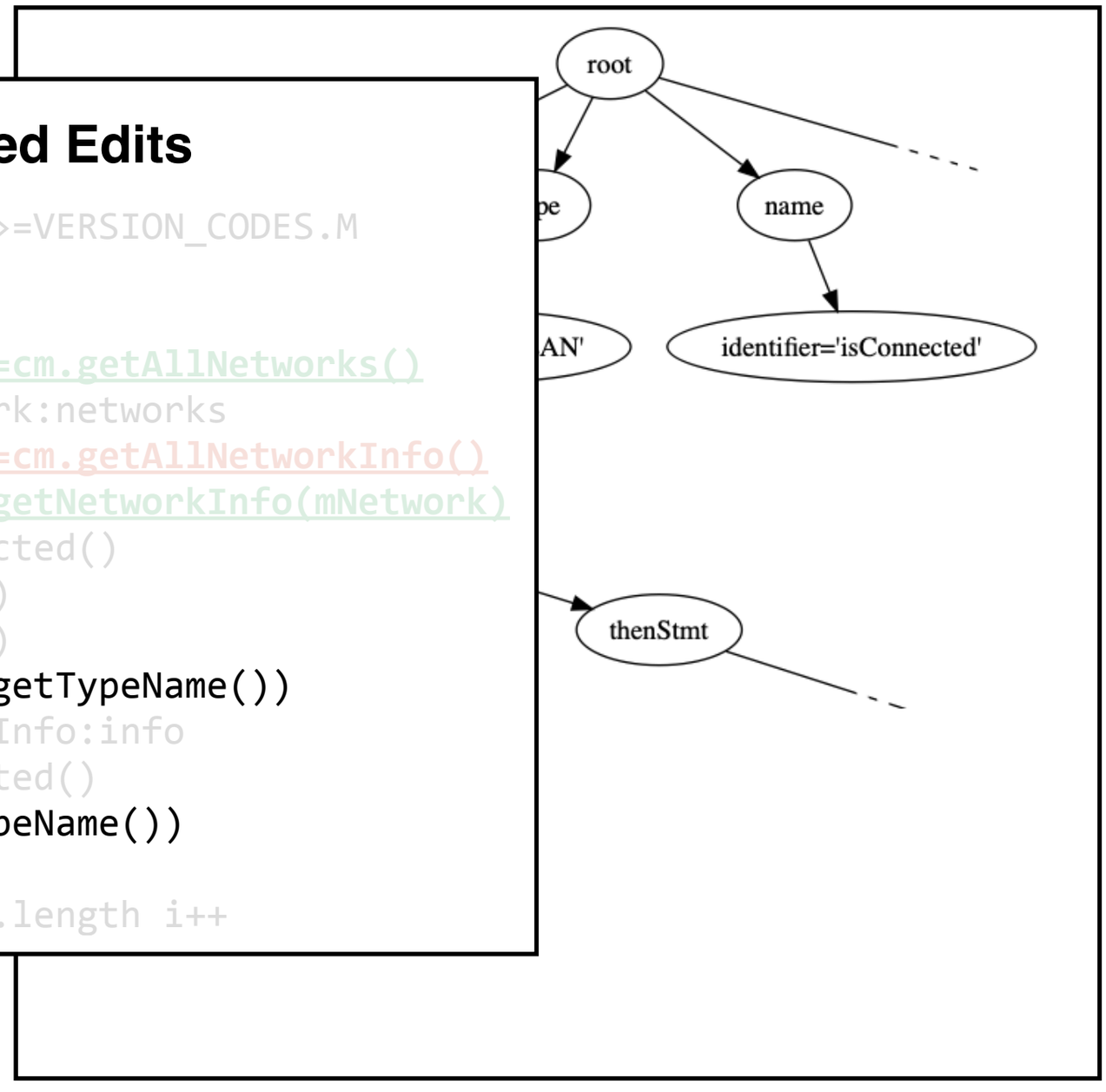
3

Compute Update Patch

Abstract Syntax Tree Before $(f_{1_{i-1}})$



Abstract Syntax Tree After (f_{1_i})



Unneeded Edits

```
INSERT  if VERSION.SDK_INT>=VERSION_CODES.M


INSERT  Network[] networks=cm.getAllNetworks()
INSERT  for Network mNetwork:networks
MOVE    NetworkInfo[] info=cm.getAllNetworkInfo()
INSERT  NetworkInfo nI=cm.getNetworkInfo(mNetwork)
UPDATE  if info[i].isConnected()
        if nI.isConnected()
MOVE    if nI.isConnected()
INSERT  Log.d(networkInfo.getTypeName())
INSERT  for NetworkInfo anInfo:info
INSERT  if anInfo.isConnected()
INSERT  Log.d(anInfo.getTypeName())
INSERT  return true
DELETE  for int i=0 i<info.length i++
```

Update Example Analysis

3

Edit Script Update Example #1

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=cm.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=cm.getAllNetworkInfo()
INSERT NetworkInfo nI=cm.getNetworkInfo(mNetwork)
UPDATE if info[i].isConnected()
       if nI.isConnected()
MOVE   if nI.isConnected()
INSERT Log.d(networkInfo.getTypeName())
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.isConnected()
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Edit Script Update Example #2

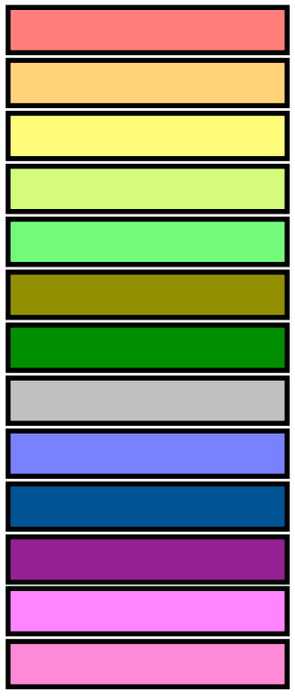
```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=cMan.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=cMan.getAllNetworkInfo()
INSERT NetworkInfo nI=cMan.getNetworkInfo(mNetwork)
UPDATE if info[i].getState()==CONNECTED
       if nI.getState()==CONNECTED
MOVE   if nI.getState()==CONNECTED
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.getState()==CONNECTED
INSERT return true
DELETE for int j=0 j<info.length j++
```

Update Example Analysis

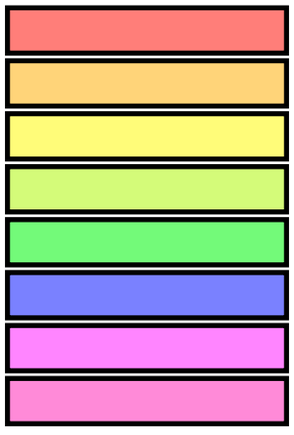
3

Find common core using Multiple Longest Common Subsequence (MLCS)

Edit Script Abstraction #1



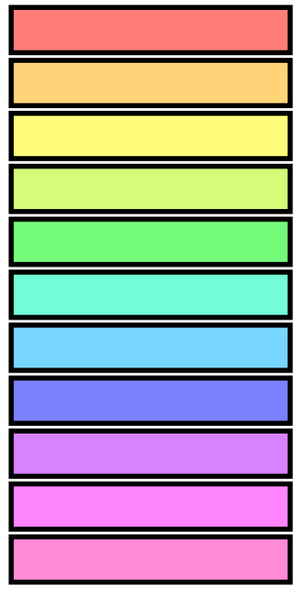
MLCS Solution



Core Proximity Value

$$\frac{|\text{MLC Solution}|}{|\text{Edit Script}|}$$

Edit Script Abstraction #2



Core Proximity Value = 0.62

Core Proximity Value = 0.72

Update Example Analysis

3

Context Variable Computation

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=$V.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=$V.getAllNetworkInfo()
INSERT NetworkInfo nI=$V.getNetworkInfo(mNetwork)
UPDATE if info[i].isConnected()
       if nI.isConnected()
MOVE   if nI.isConnected()
INSERT Log.d(networkInfo.getTypeName())
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.isConnected()
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Core Proximity Value = 0.62

Context Variables[($V,ConnectivityManager:cm)]

Update Example Analysis

3

Generic Update Patch

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=$V.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=$V.getAllNetworkInfo()
INSERT NetworkInfo nI=$V.getNetworkInfo(mNetwork)
UPDATE if info[i].isConnected()
       if nI.isConnected()
MOVE   if nI.isConnected()
INSERT Log.d(networkInfo.getTypeName())
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.isConnected()
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Core Proximity Value = 0.62

Context Variables[($V,ConnectivityManager:cm)]

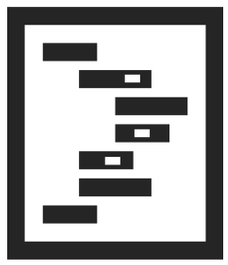
Update Example Analysis

3

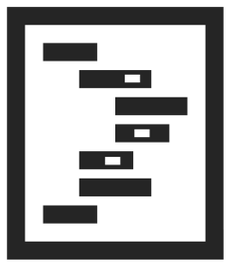
Generic Update Patch

Generic Update Patches

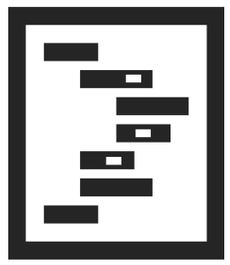
1st



2nd



3rd

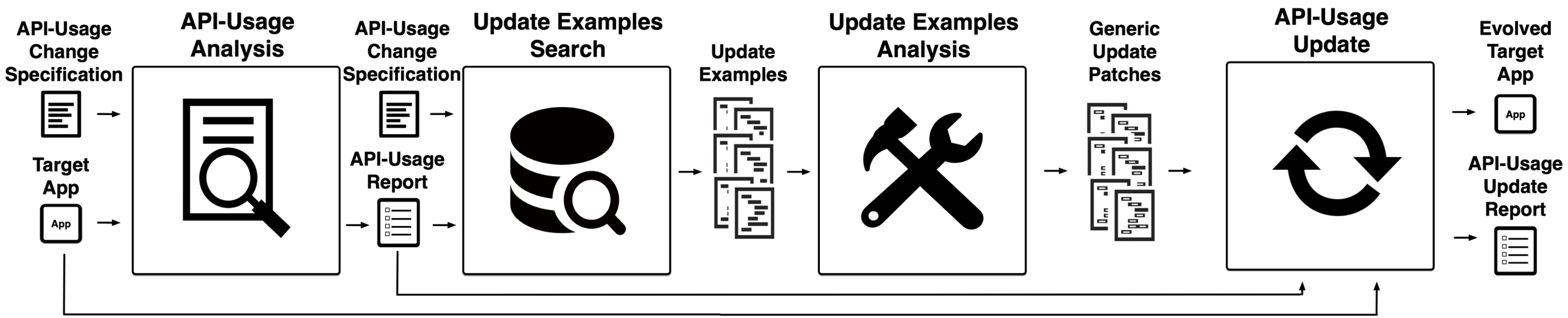


```
INSERT Log.d(anInfo.getTypeName())
INSERT return true
DELETE for int i=0 i<info.length i++
```

Core Proximity Value = 0.62

Context Variables[($V,ConnectivityManager:cm)]

AppEvolve Overview



1. Identify API usages requiring update in target app
2. Find update examples for identified API usages
3. Abstract update examples into generic update patches and rank them
4. Update and validate API usages in target app based on patches

API-Usage Update

4

Target App Code

```
public boolean hasNetwork(Context context) {
  ConnectivityManager conn = ...;
  NetworkInfo[] netInfo =
    conn.getAllNetworkInfo();
  for (int k = 0; k < netInfo; k++) {
    if (netInfo[k].getState() ==
      NetworkInfo.State.CONNECTED) {
      return true;
    } }
  return false;
}
```

Generic Update Patch

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=$V.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=$V.getAllNetworkInfo()
INSERT NetworkInfo nI=$V.getNetworkInfo(mNetwork)
UPDATE if info[i].getState()==CONNECTED
       if nI.getState()==CONNECTED
MOVE   if nI.getState()==CONNECTED
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.getState()==CONNECTED
INSERT return true
DELETE for int j=0 j<info.length j++
```

Core Proximity Value = 0.72

Context Variables[($V,ConnectivityManager:cMan)]

API-Usage Update

4

Analyze Variables in Scope

Target App Code

```
public boolean hasNetwork(Context context) {
  ConnectivityManager conn = ...;
  NetworkInfo[] netInfo =
    conn.getAllNetworkInfo();
  for (int k = 0; k < netInfo; k++) {
    if (netInfo[k].getState() ==
      NetworkInfo.State.CONNECTED) {
      return true;
    } }
  return false;
}
```

Generic Update Patch

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=cMan.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=cMan.getAllNetworkInfo()
INSERT NetworkInfo nI=cMan.getNetworkInfo(mNetwork)
UPDATE if info[i].getState()==CONNECTED
       if nI.getState()==CONNECTED
MOVE   if nI.getState()==CONNECTED
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.getState()==CONNECTED
INSERT return true
DELETE for int j=0 j<info.length j++
```

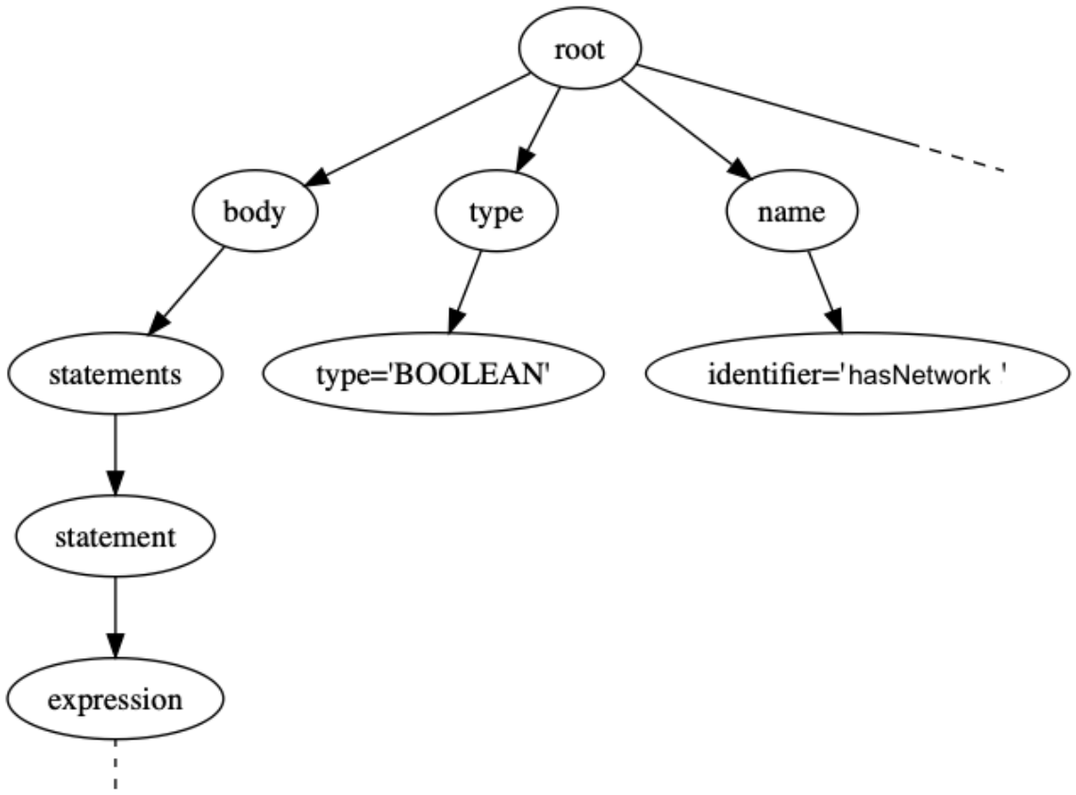
Core Proximity Value = 0.72

Context Variables[($V,ConnectivityManager:cMan)]

API-Usage Update

4

Abstract Syntax Tree Target App



Generic Update Patch

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=$V.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=$V.getAllNetworkInfo()
INSERT NetworkInfo nI=$V.getNetworkInfo(mNetwork)
UPDATE if info[i].getState()==CONNECTED
       if nI.getState()==CONNECTED
MOVE   if nI.getState()==CONNECTED
INSERT for NetworkInfo anInfo:info
INSERT if anInfo.getState()==CONNECTED
INSERT return true
DELETE for int j=0 j<info.length j++


        [($V,ConnectivityManager:conn)]
```

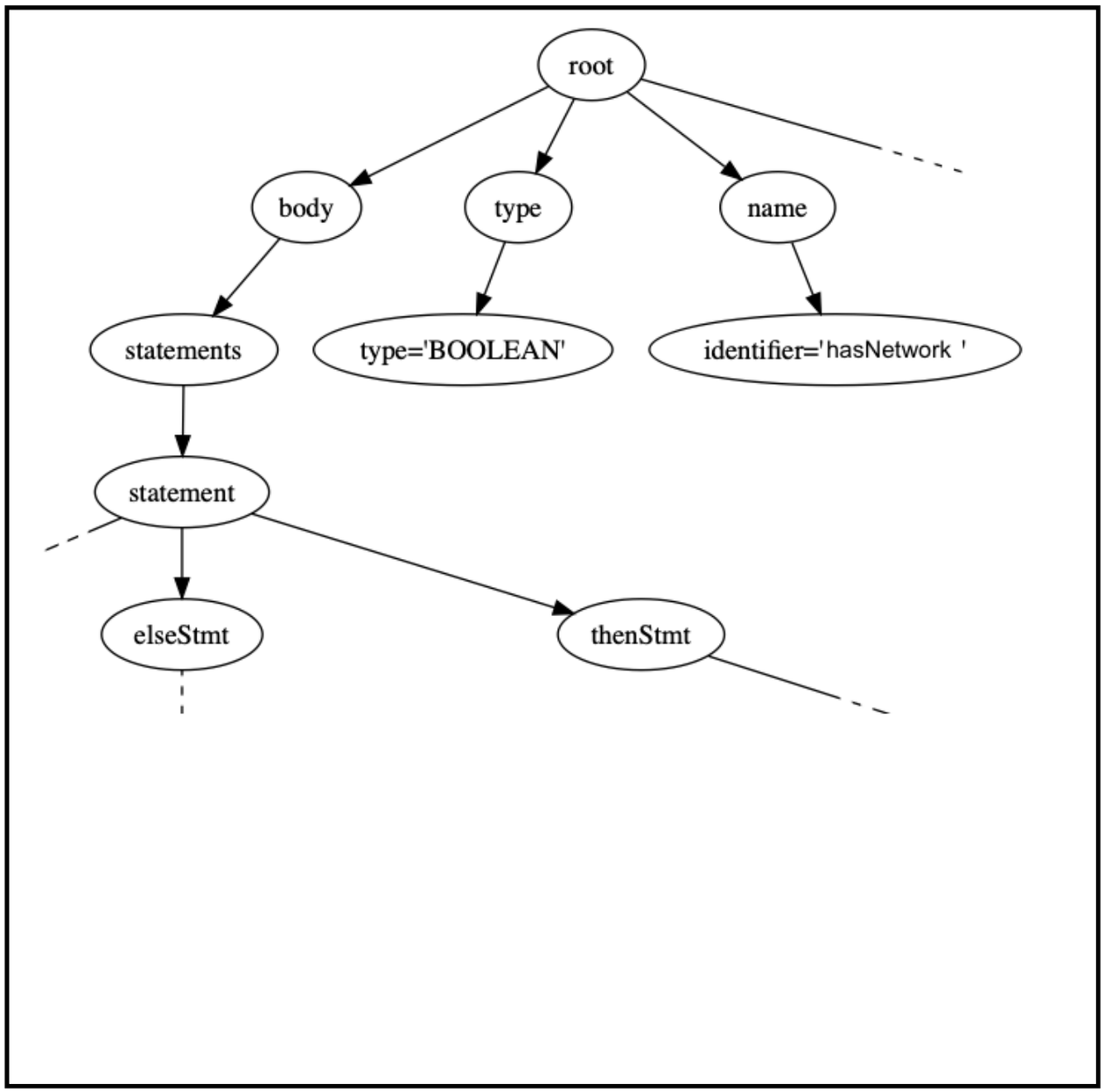
Core Proximity Value = 0.72

Context Variables `[($V,ConnectivityManager:cMan)]`

API-Usage Update

4

Updated Abstract Syntax Tree Target App



Generic Update Patch

Edit Script

```
INSERT  if VERSION.SDK_INT>=VERSION_CODES.M
INSERT  Network[] networks=$V.getAllNetworks()
INSERT  for Network mNetwork:networks
MOVE    NetworkInfo[] info=$V.getAllNetworkInfo()
INSERT  NetworkInfo nI=$V.getNetworkInfo(mNetwork)
UPDATE  if info[i].getState()==CONNECTED
        if nI.getState()==CONNECTED
MOVE    if nI.getState()==CONNECTED
INSERT  for NetworkInfo anInfo:info
INSERT  anInfo.getState()==CONNECTED
INSERT  return true
DELETE  for int j=0 j<info.length j++


          [($V,ConnectivityManager:conn)]
```

Core Proximity Value = 0.72

Context Variables `[($V,ConnectivityManager:cMan)]`

API-Usage Update

4

Updated Target App Code

```
public boolean hasNetwork(Context context) {
  ConnectivityManager conn = ... ;
  if (VERSION.SDK_INT >= VERSION_CODES.M) {
    Network[] networks = conn.getAllNetworks();
     for (Network mNetwork : networks) {
       NetworkInfo networkInfo =
         conn.getNetworkInfo(mNetwork);
       if(networkInfo.getState() ==
         NetworkInfo.State.CONNECTED) {
         return true;
       } }
  } else {
    NetworkInfo[] info =
      conn.getAllNetworkInfo();
    for (NetworkInfo anInfo : info) {
      if(anInfo.getState() ==
        NetworkInfo.State.CONNECTED) {
        return true;
      } }
  }
  return false;
}
```

Generic Update Patch

Edit Script

```
INSERT if VERSION.SDK_INT>=VERSION_CODES.M
INSERT Network[] networks=$V.getAllNetworks()
INSERT for Network mNetwork:networks
MOVE   NetworkInfo[] info=$V.getAllNetworkInfo()
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UPDATE if info[i].getState()==CONNECTED
       if nI.getState()==CONNECTED
MOVE   if nI.getState()==CONNECTED
INSERT for NetworkInfo anInfo:info
INSERT anInfo.getState()==CONNECTED
INSERT return true
DELETE for int j=0 j<info.length j++

          [($V,ConnectivityManager:conn)]
```

Core Proximity Value = 0.72

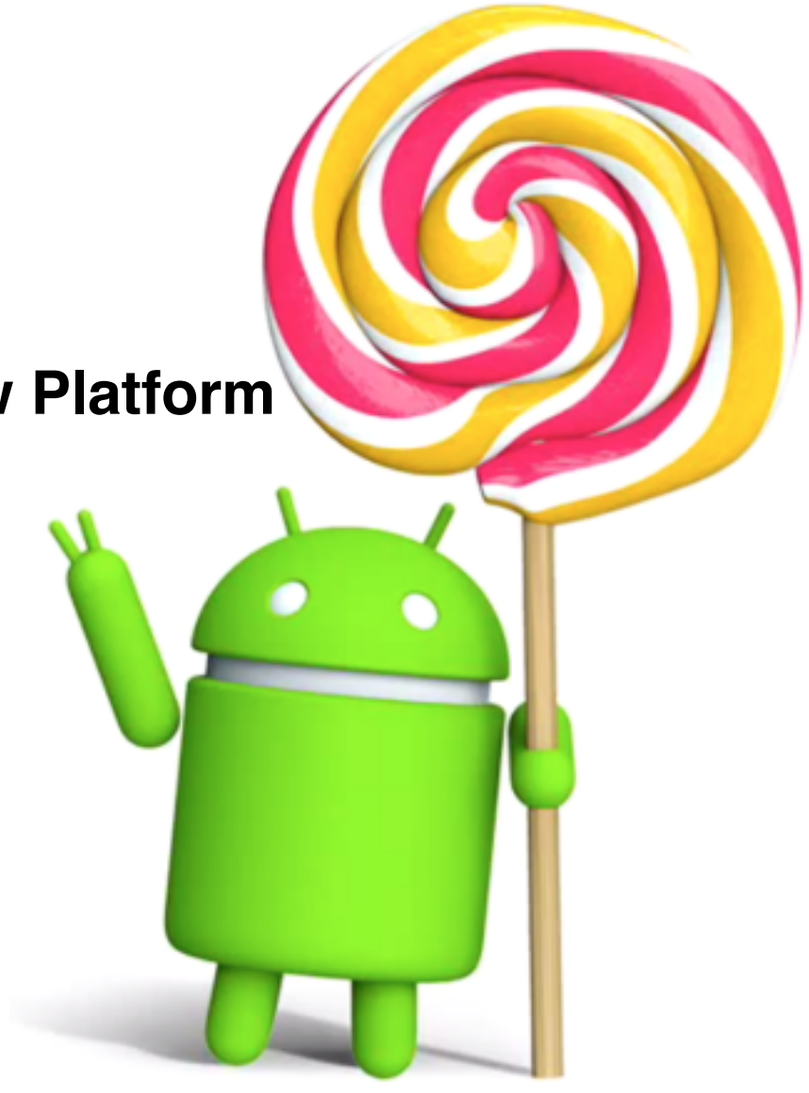
Context Variables[($V,ConnectivityManager:cMan)]

API-Usage Update

Differential Testing

Old Platform

New Platform

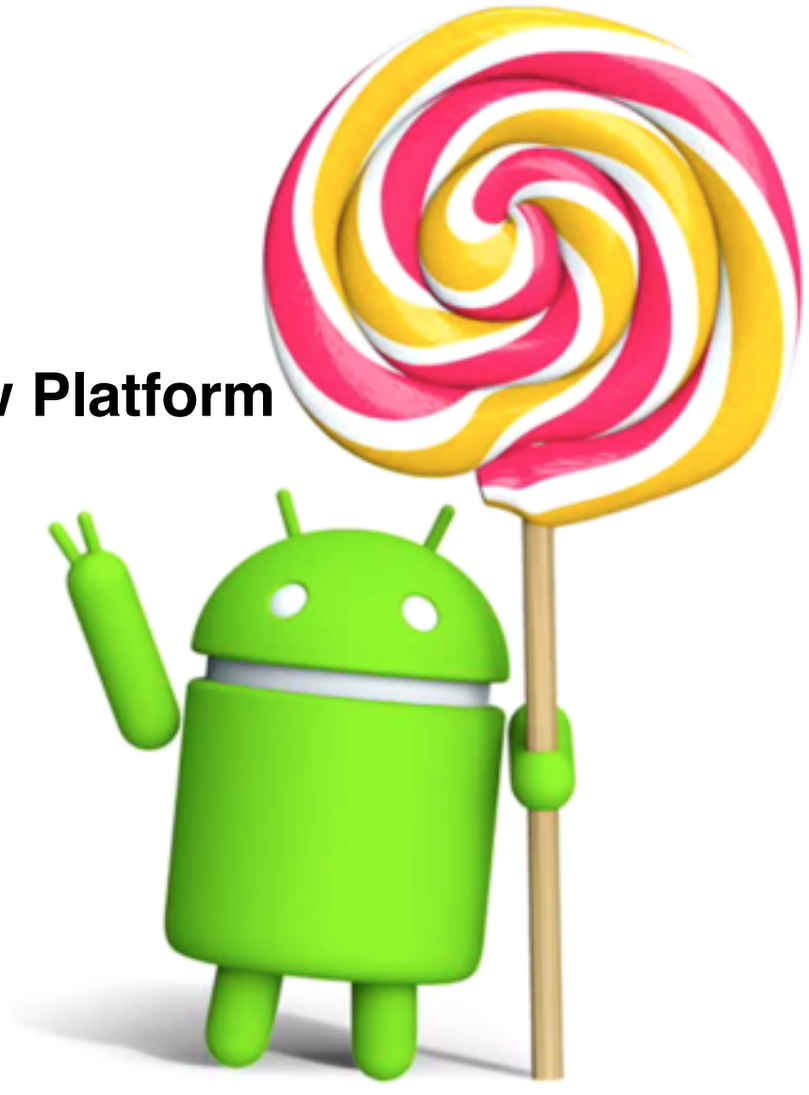


API-Usage Update

Differential Testing

Old Platform

New Platform



API-Usage Update

Differential Testing

Old Platform

New Platform

Empirical Evaluation

Research Questions

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

RQ2 (EFFICIENCY): What is the cost of running APPEVOLVE?

Empirical Evaluation

Research Questions

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Empirical Evaluation

Research Questions

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

RQ2 (EFFICIENCY): What is the cost of running APPEVOLVE?

Benchmarks and Setup

15 Apps

Lollipop	Marshmallow	Nougat
BipolAlarm	WiGLE WIFI	Symphony
Conversations	Footguy	SysLog
ParkenDD	Calendar IE	Muzei
Clean SB	Diolinux	Notes
OpenSudoku	Solar Compass	OneTwo

20 API Usages

(41 occurrences)

addAction	addGpsStatusListener	abandonAudioFocus
getAllNetworkInfo	fromHtml	getDeviceId
getCurrentHour	release	requestAudioFocus
getCurrentMinute	removeGpsStatusListener	saveLayer
setCurrentHour	shouldOverrideUrlLoading	setAudioStreamType
setCurrentMinute	startDrag	vibrate(long)
setTextAppearance		vibrate(long[],int)

Setup

- Ran technique on benchmarks
- Measured successful update and validation rate
- Measured execution time

Benchmarks and Setup

15 Apps

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setCurrentHour	shouldOverrideUrlLoading	setAudioStreamType
setCurrentMinute	startDrag	vibrate(long)
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Setup

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Benchmarks and Setup

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setCurrentHour	shouldOverrideUrlLoading	setAudioStreamType
setCurrentMinute	startDrag	vibrate(long)
setTextAppearance		vibrate(long[],int)

Setup

- Ran technique on benchmarks
- Measured successful update and validation rate
- Measured execution time

Evaluation: Effectiveness

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

Overall Effectivness

- **17/20 (85%)** successful update rate (for API usages)
- **37/41 (90%)** successful update rate (for API-usage occurrences)
- **25/37 (68%)** automatic validation rate (for API-usage occurrences)

Details

- In **19/20** cases, APPEVOLVE could find update examples
- In **14/19** cases, the number of relevant edits is lower than the number of AST edits
- In **11/19** cases, the core proximity value is different from its minimum and maximum

APPEVOLVE is effective in automatically updating API usages.

Evaluation: Effectiveness

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

Overall Effectivness

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Evaluation: Effectiveness

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

Overall Effectivness

- **17/20 (85%)** successful update rate (for API usages)
- **37/41 (90%)** successful update rate (for API-usage occurrences)
- **25/37 (68%)** automatic validation rate (for API-usage occurrences)

Details

- In **19/20** cases, APPEVOLVE could find update examples
- In **14/19** cases, the number of relevant edits is lower than the number of AST edits
- In **11/19** cases, the core proximity value is different from its minimum and maximum

APPEVOLVE is effective in automatically updating API usages.

Evaluation: Efficiency

RQ2 (EFFICIENCY): What is the cost of running APPEVOLVE?

Average Execution Time			
API-Usage Analysis	Update Examples Search	Update Examples Analysis	API-Usage Update
28s	**10h27m**	2s204ms	20s

The cost of the **update examples search** phase dominates the cost of the other phases.

Future Work

Handle updates that span across multiple methods

Automatically compute API change specifications

Improve validation through differential testing

Investigate use of AppEvolve in other contexts (e.g., web apps)

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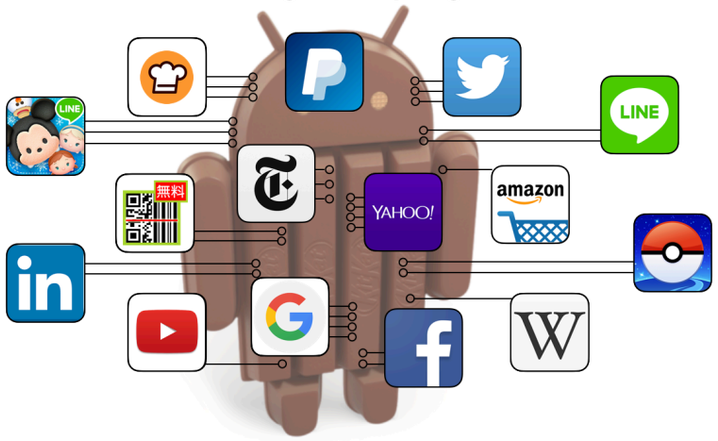
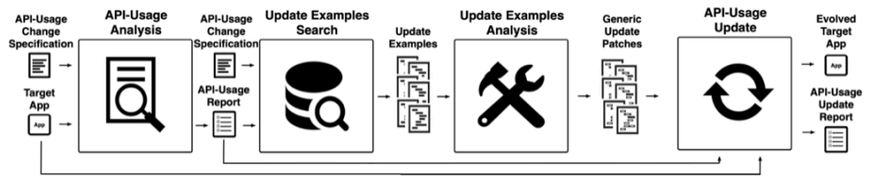
Summary

Platform

Tight Coupling



APPEVOLVE Overview



1. Identify API usages in target app that require update
2. Find update examples for identified API usages
3. Abstract and rank update examples into generic update patches
4. Update and validate API usages in target app based on patches

Empirical Evaluation

Research Questions

RQ1 (EFFECTIVENESS): Can APPEVOLVE update API usages in real-world apps?

RQ2 (EFFICIENCY): What is the cost of running APPEVOLVE?

Future Work

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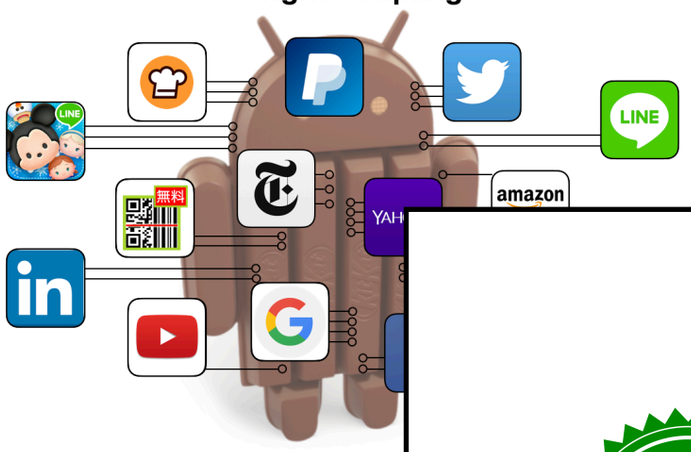
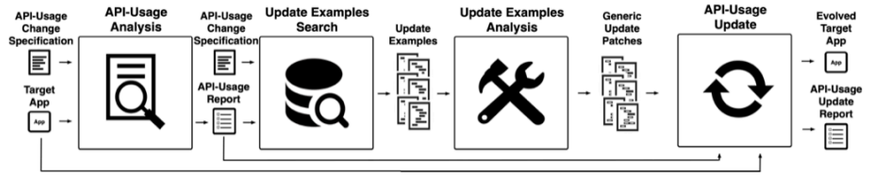


AppEvolve Overview



3 Abstract and rank update examples into generic update patches

4 Update and validate API usages in target app based on patches

Artifact

https://b.gatech.edu/2JKkpWV

Empirical Ev

Research Que

RQ1 (Effectiveness): Can AppEvolve upd

RQ2 (Efficiency): What is the cost of running AppEvolve?

re Work

ultiple methods

Automatically compute API change specifications

Improve validation through differential testing

Investigate use of AppEvolve in other contexts (e.g., web apps)

Related Work

Example Based Program Update

SYDIT, LASE, RASE, MEDITOR, REFAZER, ARES,…

Other Techniques

ICTAPIFINDER, CHANGEDISTILLING