Return of ECC dummy point additions: SPA on efficient P-256 implementation

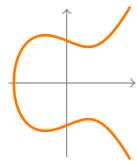
Andy Russon

3 June 2021

orange™

Introduction

- Secure cryptography: avoid secret dependent behavior in execution



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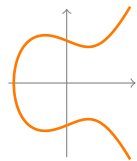

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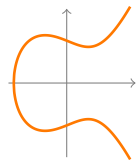

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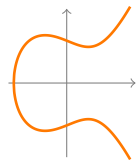

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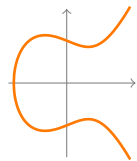
- Example of elliptic curve P-256:
  - Popular curve, notably for digital signatures (with ECDSA)
  - Efficient implementation in assembly available (OpenSSL and its forks)[1]



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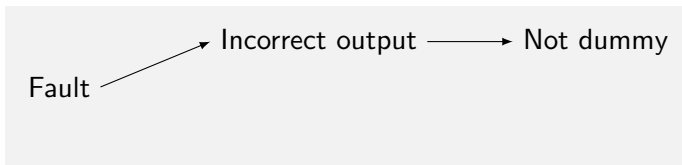

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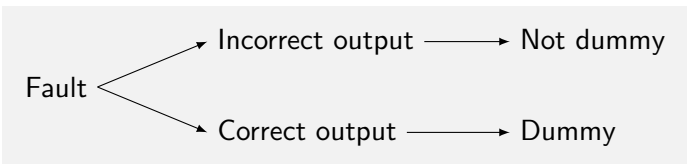
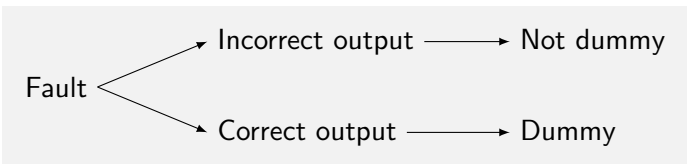


[2] "Exploiting dummy codes in Elliptic Curve Cryptography implementations", SSTIC 2020

- Previously at SSTIC[2]
  - Fault injection to detect dummy operation
  - Not easy (material, timing, etc)
  - Produces many invalid outputs: hard to pass unnoticed



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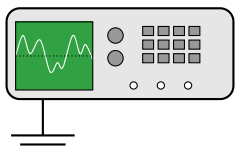
In this presentation

- Goal: recover an ECDSA private key
  - On OpenSSL with the P-256 assembly optimized implementation
  - With power analysis to detect dummy operations



Plan

Assembly optimized P-256 implementation

ECDSA secret nonce $k = 1101101101110110110 \quad \cdots \quad 1111011100100100100000$

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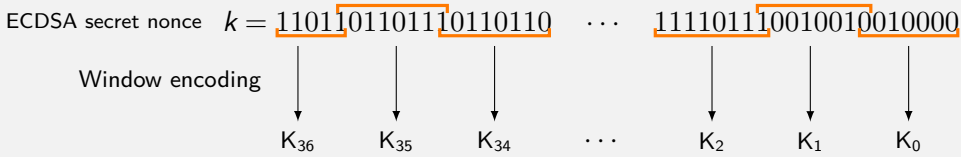

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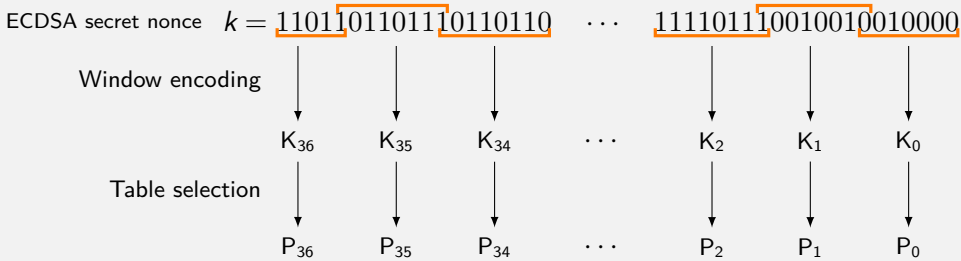

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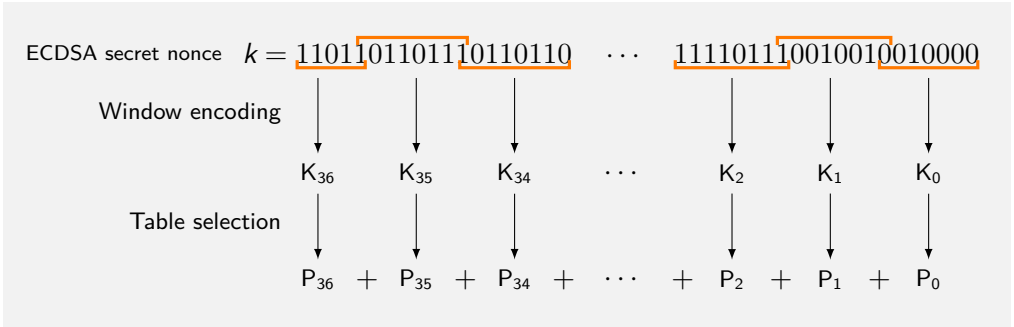

function `ecp_nistz_point_add_affine`

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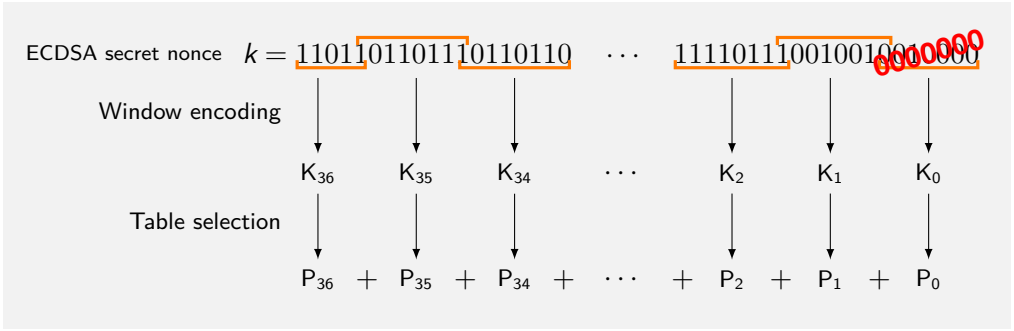

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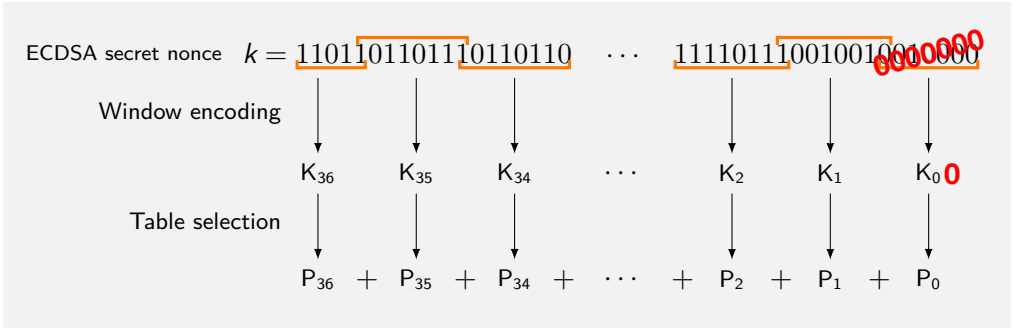

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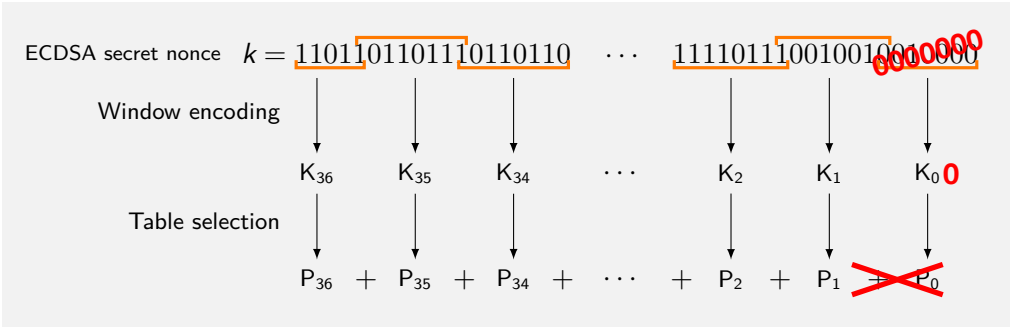

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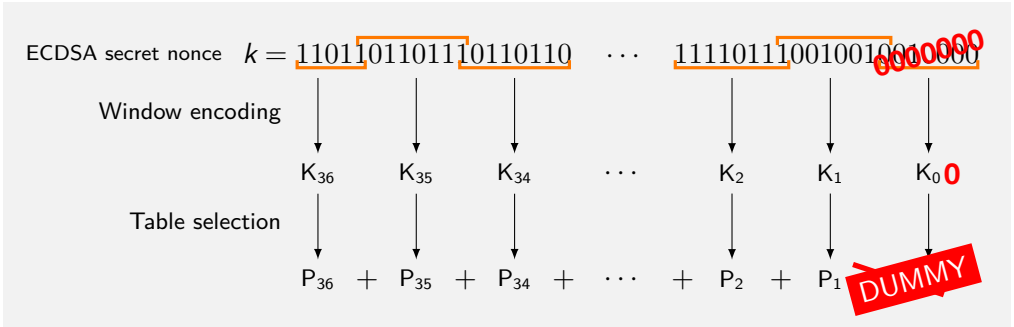

- Always 36 execution function `ecp_nistz_point_add_affine`

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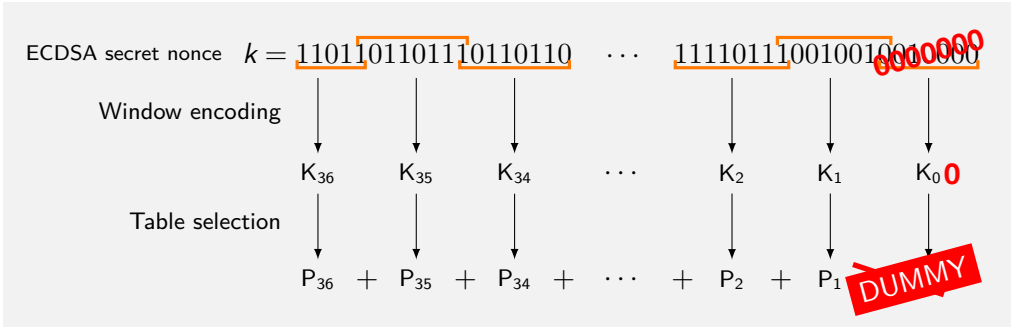

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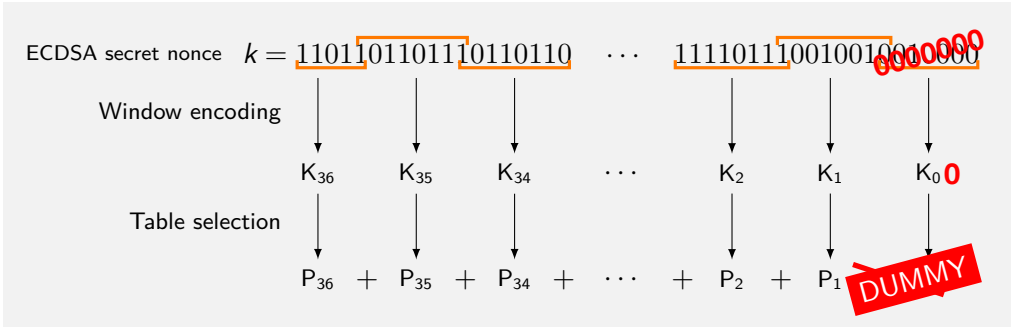
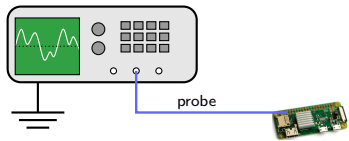


- Always 36 execution function `ecp_nistz_point_add_affine`
- Null window $\Rightarrow$ dummy point addition
- First window: K_0 is 7 lowest bits of k

Plan

Steps of the attack

1. Capture power consumption of an ECDSA signature generation



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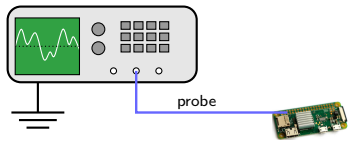

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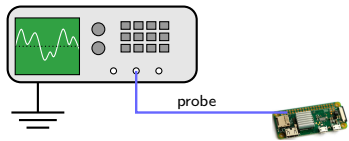

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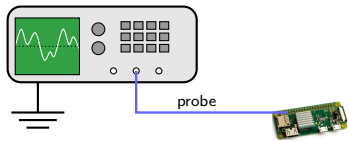
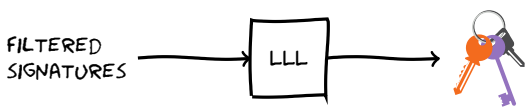


2. Keep the signature if there is a lower power consumption during the **first** point addition
3. Repeat until enough signatures are collected (around 37)
4. Recover the private key from the signatures



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- `TracerGrind`: a `Valgrind` plugin to monitor processes
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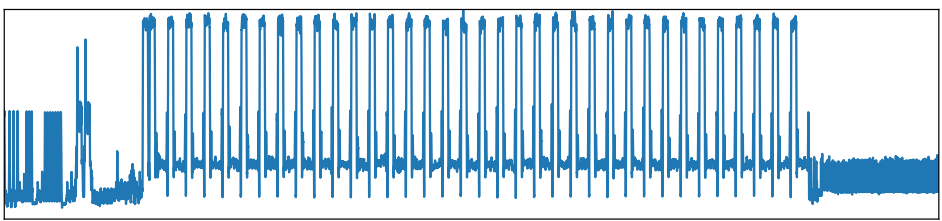

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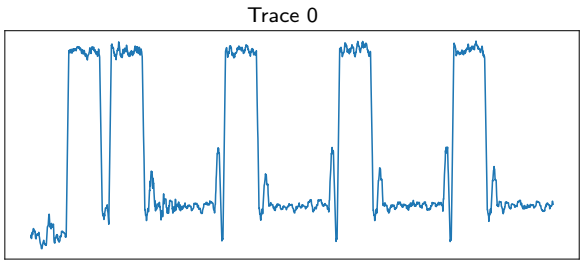

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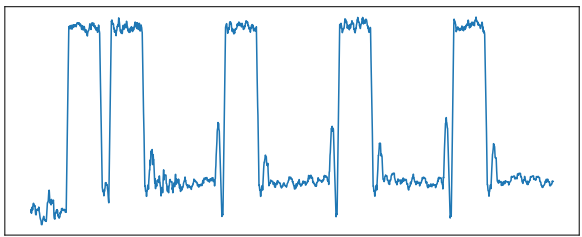

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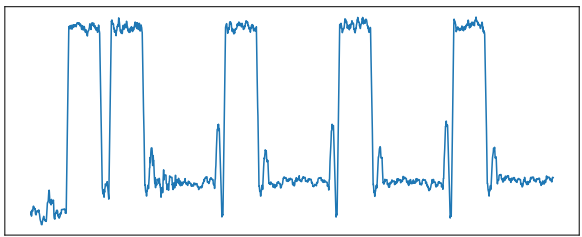

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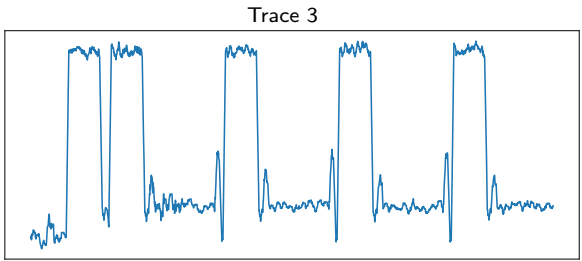

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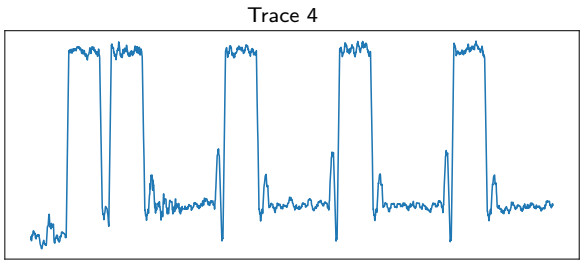

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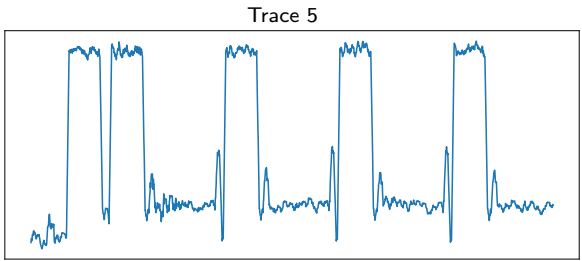

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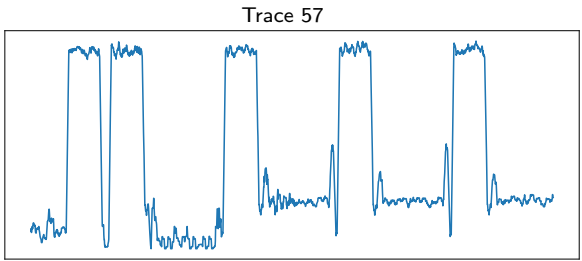

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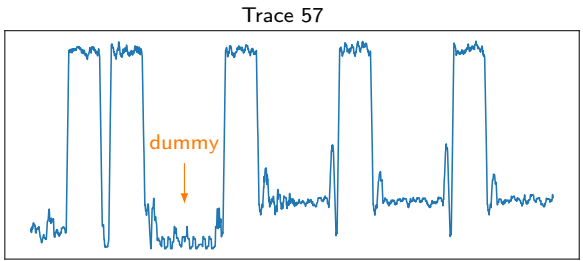

How many signatures we need?

- Number of signatures:
  - 7 lowest bits of k null: 1 out of 128 signatures on average
  - Key recovery: 37 signatures (or more) if 7 bits of nonce known
  - Total: $37 \times 128 = 4738$

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  - Total: $37 \times 128 = 4738$
- Clustering the traces:
  - `GaussianMixture` class in `Scikit-learn` Python library
  - Classify the traces in **two** components

```
from sklearn import mixture
gm = mixture.GaussianMixture(n_components=2)
results = gm.fit_predict(traces)
```

Example

- Trace generation:

```
python3 simulation.py -b /usr/local/bin/openssl --privkey privkey.pem
  --working-dir test -n 6000 --bounds 1844200 1844500
```

Tools available at `https://github.com/orangecertcc/ecdummyrpa`

Example

- Trace generation:

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- Analysis:

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```

- Analysis:

```
python3 analysis.py --pubkey pubkey.pem --working-dir test -n 6000
```

- Results:

```
Loading 6000 traces...
Clustering of the traces...
Size of clusters: 5950, 50
Lattice attack: recovering of the key with 37 signatures...
Lattice attack: recovering of the key with 38 signatures...
SUCCESS!
The private key is deb867c4cf52002d7d8cc2e440d16c8c75c7844fdb142ea8c1a1f48b411b0251
```

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Plan

Handling of the dummy point addition

`ecp_nistz_point_add_affine`:

Input: $P = (X_1, Y_1, Z_1)$, $Q = (x_2, y_2)$ **Output:** $P + Q = (X_3, Y_3, Z_3)$

$\texttt{in1infty} \leftarrow (Z_1 == 0)$	$t_5 \leftarrow 2 \cdot t_1$
$\texttt{in2infty} \leftarrow (x_2, y_2) == (0, 0)$	$X_3 \leftarrow t_6 - t_5$
$t_0 \leftarrow {Z_1}^2$	$X_3 \leftarrow X_3 - t_7$
$t_1 \leftarrow x_2 \cdot t_0$	$t_2 \leftarrow t_1 - X_3$
$t_2 \leftarrow t_1 - X_1$	$t_3 \leftarrow Y_1 \cdot t_7$
$t_3 \leftarrow t_0 \cdot Z_1$	$t_2 \leftarrow t_2 \cdot t_4$
$Z_3 \leftarrow t_2 \cdot Z_1$	$Y_3 \leftarrow t_2 - t_3$
$t_3 \leftarrow t_3 \cdot y_2$	**if** $\texttt{in1infty}$ **then**
$t_4 \leftarrow t_3 - Y_1$	$\quad (X_3, Y_3, Z_3) \leftarrow (x_2, y_2, 1)$
$t_5 \leftarrow {t_2}^2$	**if** $\texttt{in2infty}$ **then**
$t_6 \leftarrow {t_4}^2$	$\quad (X_3, Y_3, Z_3) \leftarrow (X_1, Y_1, Z_1)$
$t_7 \leftarrow t_5 \cdot t_2$	**return** (X_3, Y_3, Z_3)
$t_1 \leftarrow X_1 \cdot t_5$	

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- If $K_0 = 0$, then P is initiliaze with $(0, 0, 0)$
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$\texttt{in1infty} \leftarrow \textbf{true}$	$t_5 \leftarrow 2 \cdot t_1$
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$t_0 \leftarrow \mathbf{0}^2$	$X_3 \leftarrow X_3 - t_7$
$t_1 \leftarrow x_2 \cdot t_0$	$t_2 \leftarrow t_1 - X_3$
$t_2 \leftarrow t_1 - X_1$	$t_3 \leftarrow Y_1 \cdot t_7$
$t_3 \leftarrow t_0 \cdot Z_1$	$t_2 \leftarrow t_2 \cdot t_4$
$Z_3 \leftarrow t_2 \cdot Z_1$	$Y_3 \leftarrow t_2 - t_3$
$t_3 \leftarrow t_3 \cdot y_2$	**if** `in1infty` **then**
$t_4 \leftarrow t_3 - Y_1$	$(X_3, Y_3, Z_3) \leftarrow (x_2, y_2, 1)$
$t_5 \leftarrow {t_2}^2$	**if** `in2infty` **then**
$t_6 \leftarrow {t_4}^2$	$(X_3, Y_3, Z_3) \leftarrow (X_1, Y_1, Z_1)$
$t_7 \leftarrow t_5 \cdot t_2$	**return** (X_3, Y_3, Z_3)
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Handling of the dummy point addition

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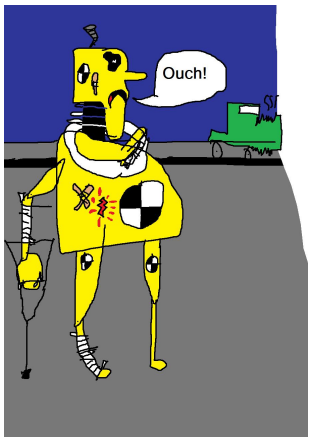
ignore previous calculation

Plan

Conclusion and mitigations



- SPA on efficient implementation of elliptic curve P-256
- Less than 5000 traces to recover a private key
- Mitigations:
  - Dummy additions with random values instead of zero
  - Use regular algorithms that do not need dummy additions
- Proof of concept and tools available as a Docker:

  `https://github.com/orangecertcc/ecdummyrpa`