



Mismeasure For Measure

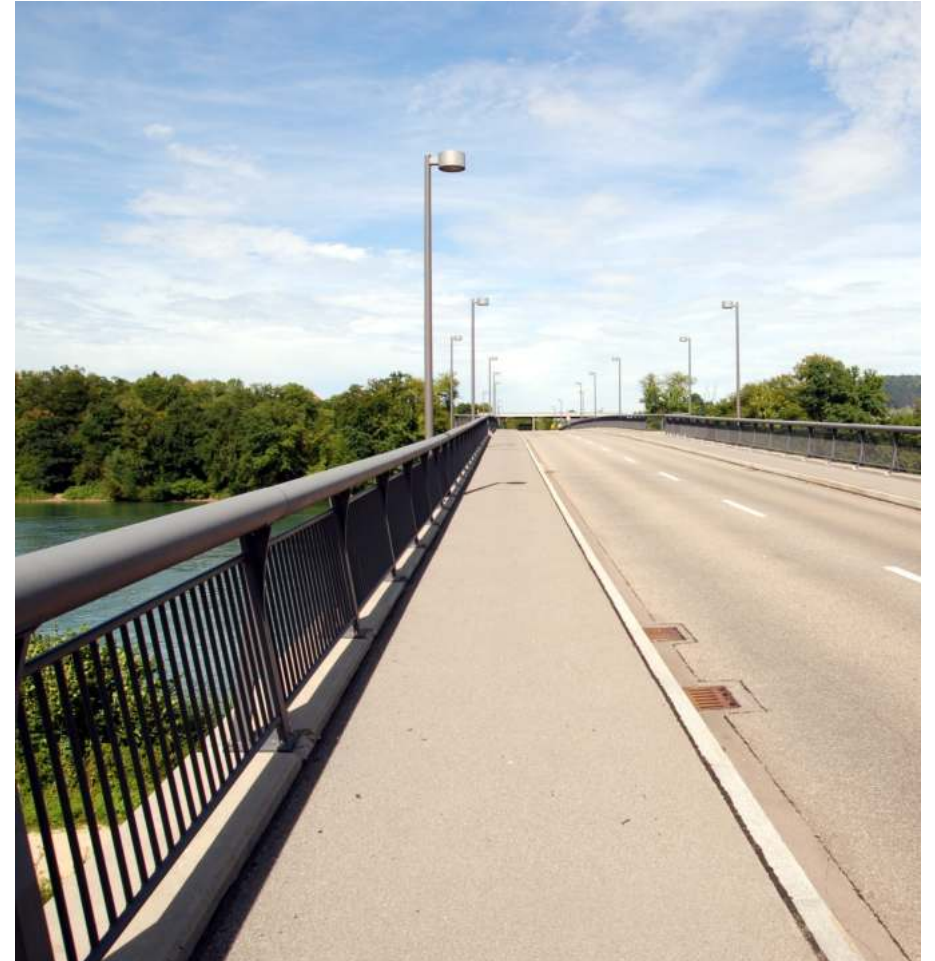
PART 2 OF N

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Bridge across the Rhine

- Since 2004, Hochrheinbrücke bridge **connects** small German town of **Laufenburg** with Swiss **Laufenburg**
 - the bridge is **225 m** long and **11.2 m** wide, and cost **12** million Swiss Francs
- The older Rhine bridge, which connects the two towns, *was no longer sufficient to handle the growing cross-border traffic* in the early 2000s



Building the bridge

- Each country began construction on its respective side and **were to meet in the middle**



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What could possibly go wrong?

There is more than one official Sea Level

- In Germany and Switzerland, the **sea level is used as a reference for height** information
 - sea level cannot be seen directly from Laufenburg ;-)
 - a more precise reference point is needed



The Amsterdam Sea Level

- Since 1878, for the normal height zero
Germany uses the so-called Amsterdam level
- This zero reference was defined by the
average level of the North Sea there during
the period 1 September of 1683 and 1684 and
marked by marble tablets



The Reference Stone of Neptune

- In **Switzerland**, the reference point is the **Repère Pierre du Niton (Neptune's Stone)**
 - a measuring point mounted *on a rock deposited by a glacier in the port of Geneva*
 - the actual height of this stone was *corrected to 373.6 m* above the *sea level reference in Marseilles* (on the **Mediterranean**) in 1902



A known mean sea level problem

- The **German** reference for sea level uses the **North Sea**
- The **Swiss** reference for sea level used the **Mediterranean Sea**
- The reference altitude used in Switzerland is **270 millimeters** lower than in Germany

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“The difference of **27 cm** was certainly known, and everything had been drawn up correctly on paper” explained Beat von Arx, project manager at the department of Civil Works of the Swiss canton Aargau.

A Human Error

- Even during the **early construction phase**, it became clear that **something was wrong**
- At Christmas 2003, the bridge builders received an unpleasant gift
 - a clear *difference in height* was clearly evident on both sides and *more than 27 centimeters*

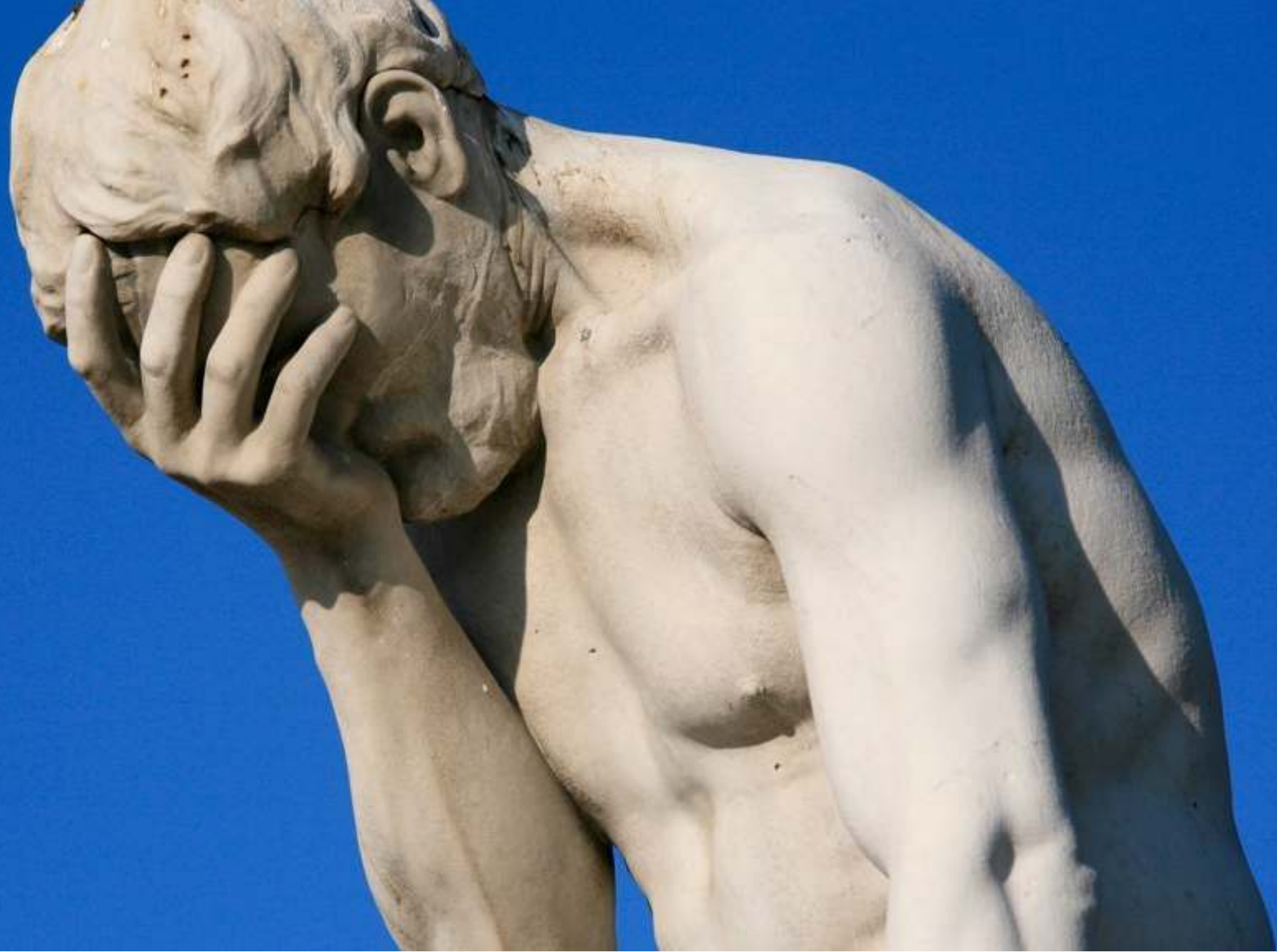
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- **A sign error was hidden in the height calculations of the responsible engineering office on the Swiss side**

Instead of 27 cm higher the Swiss built 27 cm lower which doubled the difference to 54 cm.



Happy ending

- Because **the error was discovered in time**, it was reportedly corrected *without incurring additional costs*
- *On the German side, the bridge was lowered accordingly*
- Eventually the two sides connected

mp-units

- A Physical Quantities and Units library for C++
- MIT License
- Hosted on Github at [mpusz/mp-units](https://github.com/mpusz/mp-units)
- Extensive documentation at mpusz.github.io/mp-units
- Available in the Compiler Explorer (Thank You Matt Godbolt!!!)

How to prevent such errors with `mp-units`?

(<https://godbolt.org/z/jbnx6MW1z>)

```
// reference points for both systems
constexpr struct amsterdam_sea_level : absolute_point_origin<isq::altitude> {} amsterdam_sea_level;
constexpr quantity_point<isq::altitude[cm], amsterdam_sea_level> mediterranean_sea_level(-27 * cm);
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// altitude quantity point types expressing both systems
using altitude_DE = quantity_point<isq::altitude[m], amsterdam_sea_level>;
using altitude_CH = quantity_point<isq::altitude[m], mediterranean_sea_level>;
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```
// expected bridge altitude in a specific reference system
quantity_point<isq::altitude[m], amsterdam_sea_level> expected_bridge_alt(330 * m);
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```
// some nearest landmark altitudes on both sides of the river
// equal but not equal ;-)
altitude_DE landmark_alt_DE(300 * m);
altitude_CH landmark_alt_CH(300 * m);

// artificial measured deltas from the landmarks to the bridge base on both sides of the river
auto delta_DE = isq::height(3 * m);
auto delta_CH = isq::height(-2 * m);

// artificial altitude of the bridge base on both sides of the river
auto bridge_base_alt_DE = landmark_alt_DE + delta_DE;
auto bridge_base_alt_CH = landmark_alt_CH + delta_CH;
```

How to prevent such errors with `mp-units`? (<https://godbolt.org/z/jbnx6MW1z>)

```
// artificial height of the required bridge pilar height on both sides of the river
auto bridge_pilar_height_DE = expected_bridge_alt - bridge_base_alt_DE;
auto bridge_pilar_height_CH = expected_bridge_alt - bridge_base_alt_CH;
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// artificial height of the required bridge pilar height on both sides of the river
auto bridge_pilar_height_DE = expected_bridge_alt - bridge_base_alt_DE;
auto bridge_pilar_height_CH = expected_bridge_alt - bridge_base_alt_CH;
```

```
std::cout << "Bridge pilars height:\n";
std::cout << "- Germany:      " << bridge_pilar_height_DE << '\n';
std::cout << "- Switzerland: " << bridge_pilar_height_CH << '\n';

// artificial bridge altitude on both sides of the river in both systems
auto bridge_road_alt_DE = bridge_base_alt_DE + bridge_pilar_height_DE;
auto bridge_road_alt_CH = bridge_base_alt_CH + bridge_pilar_height_CH;

std::cout << "Bridge road altitude:\n";
std::cout << "- Germany:      " << bridge_road_alt_DE << '\n';
std::cout << "- Switzerland: " << bridge_road_alt_CH << '\n';

std::cout << "Absolute bridge road altitude:\n";
std::cout << "- Germany:      " << bridge_road_alt_DE.absolute() << '\n';
std::cout << "- Switzerland: " << bridge_road_alt_CH.absolute() << '\n';
```

Bridge pilars height:

- Germany: 27 m
- Switzerland: 3227 cm

Bridge road altitude:


- Germany: 330 m AMSL(DE)
- Switzerland: 33027 cm AMSL(CH)

Absolute bridge road altitude:

- Germany: 330 m
- Switzerland: 33000 cm

Bonus Slides

- There are **proposals to use a universal geoid model** of the Earth
 - aided by GPS and atomic clock measurements
- When we will start to *use the Earth's center as a reference*, considerable changes can occur
 - the peak of **Ecuador's Chimborazo is a only 6310 m** above the local sea level
 - because of the Earth's deviation from a sphere, this peak is **over 2 Kilometers farther from the Earth's center than Mount Everest**

The background is a solid yellow color. It is decorated with several black geometric shapes, primarily parallelograms and triangles, arranged in a pattern that suggests a 3D perspective or a stylized architectural design. These shapes are positioned around the edges and corners of the frame.

CAUTION
Programming
is addictive
(and too much fun)