

# *What can Industry 4.0 learn from SE?*

CIRP GA 2016  
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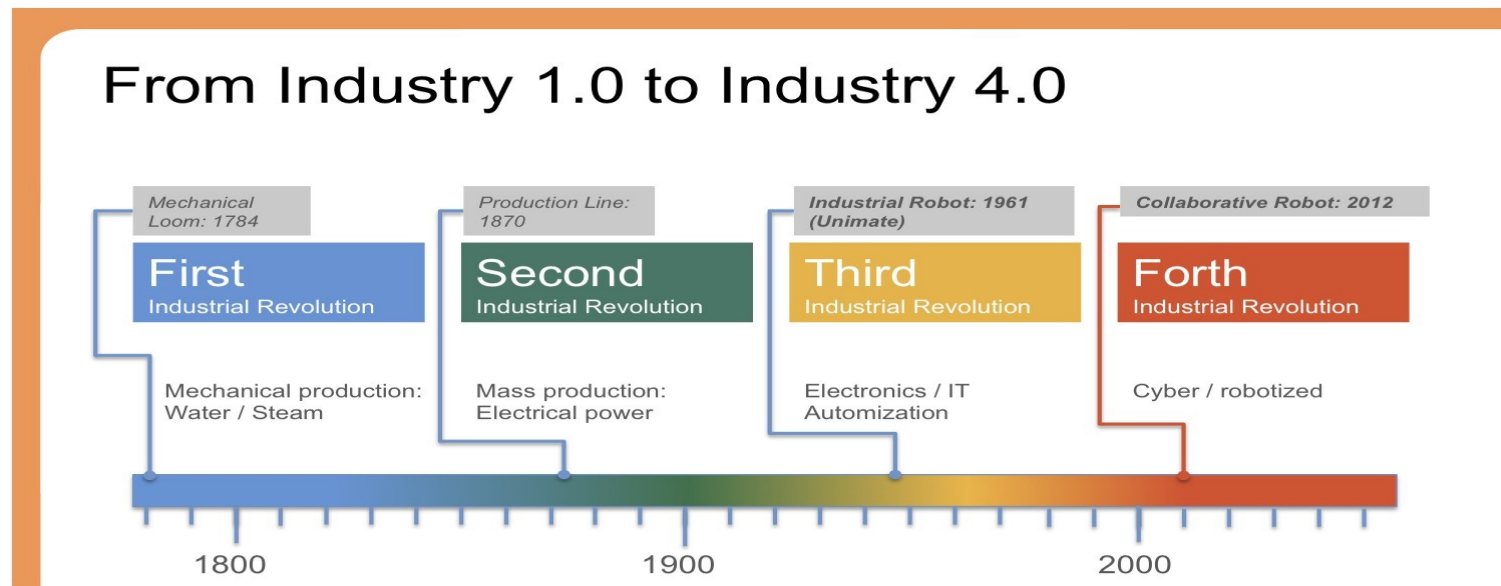
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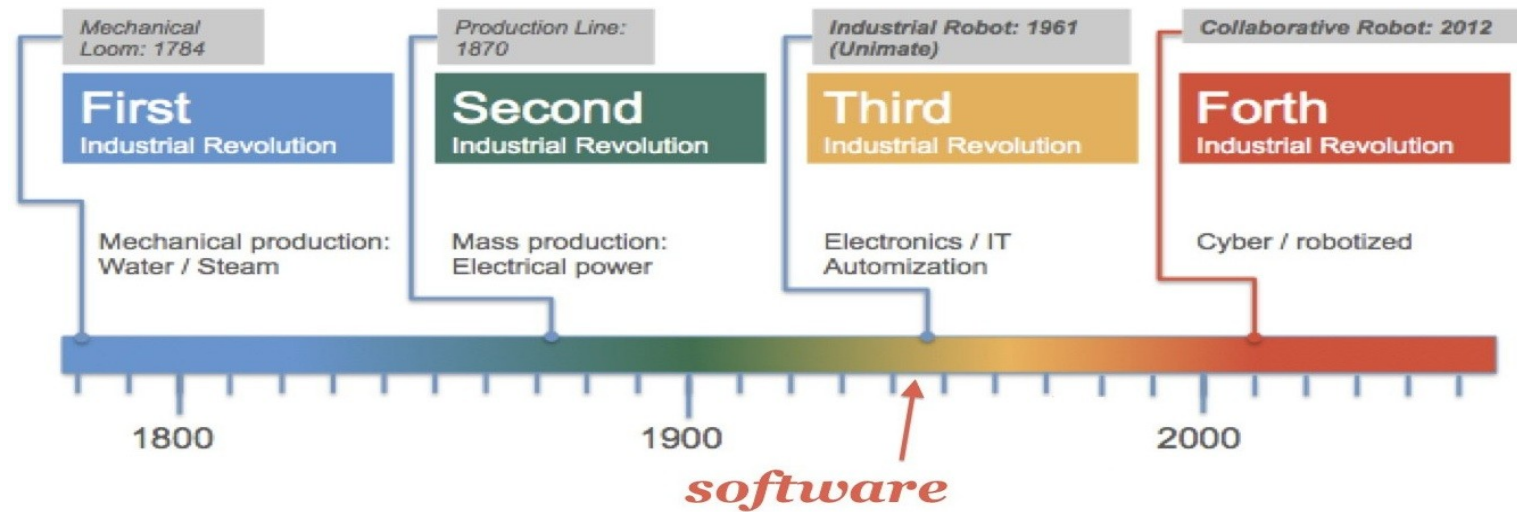


```
for i = 1 to 4 do {industry (i );}
```



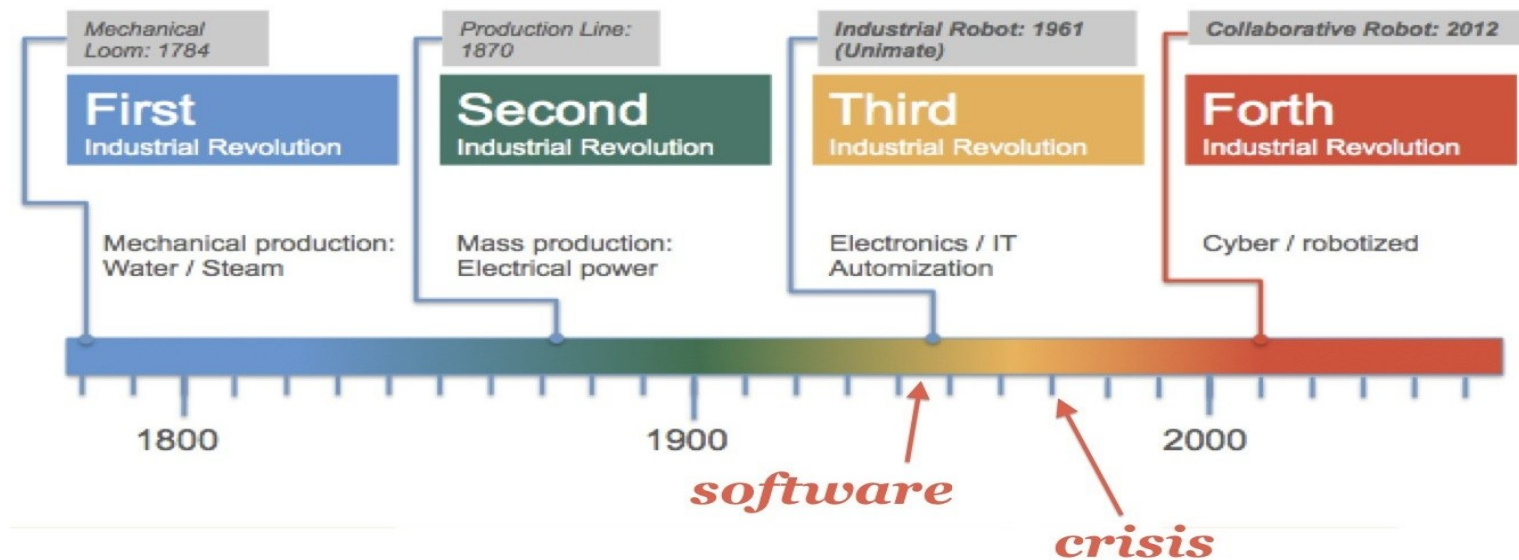
Credit: **nelmia** Robotics Insight (2015)

# Turning point



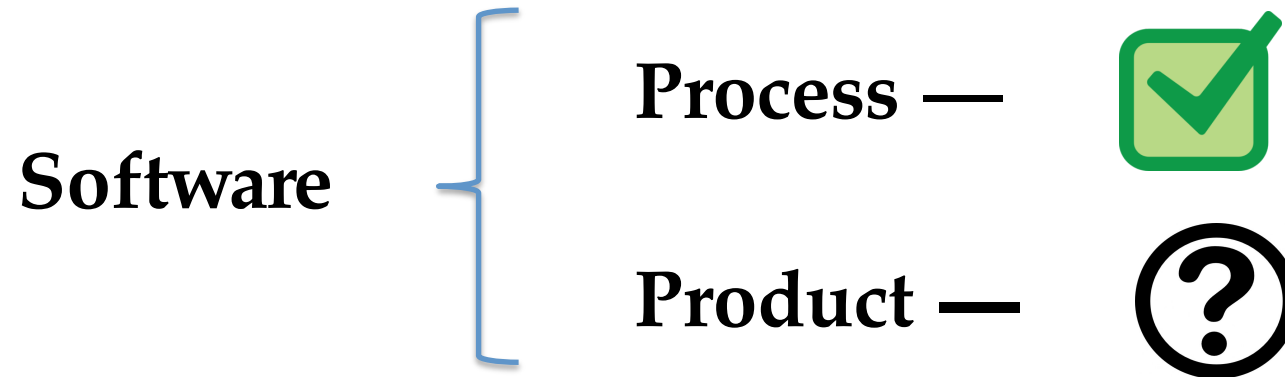
( "L'enfant terrible" is born )

# Crisis



1st NATO Conference on **Software Engineering**,  
Darmstadt, October 1968

## Meanwhile (50 years)



“Traditional” engineering principles apply to **process** but  
not so well to **product** — *why?*

## “L'enfant terrible”

**Hardware** and other “traditional” industrial **products** fabricated according to the *laws of physics*.

**Software** not governed by the laws of *physics*:

- it does not weight / does not smell
- it does not warm up / cool down
- it is chemically neutral ...

Anthony Oettinger (ACM President, 1967):

*“(...) the scientific, rigorous component of computing, is more like **mathematics** than it is like **physics**”*



## Software = mathematics in motion

Can one *pretend* that **software production** is not affected by its **special nature** and simply move on?

People have tried to do so, for 50 years, with little success.

Still Oettinger (**already** in 1967):

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*"It is a matter of **complexity**. Once you start putting thousands of these instructions together you create a **monster** which is **unintelligible** to anyone save its creator and, most of the time, unfortunately even to the creator."*

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## Industry 4.0 and software

**Industry 4.0 to rely on highly sophisticated software on an unprecedented scale.**

Billions, not thousands, of lines of code  
required to

**for all do** {*human* := *robot*}

Software **correctness** and **robustness** therefore essential.





## What have we learned about software?

Software lives on **abstraction**:

*"The purpose of **abstraction** is not to be **vague**, but to create a new semantic level in which one can be **absolutely precise**." (E. Dijkstra)*

From a Robot Programming Tutorial:

*"The fundamental challenge of all **robotics** is this: It is impossible to ever know the true state of the **environment**. A **robot** can **only guess** the state of the real world based on measurements returned by its **sensors**."*

We have developed a sound theory for (safe) **guessing** called **abstract interpretation** — widely used in *program analysis* tools nowadays.

# Type oriented programming

Something we've also learned is how important **types** are.

Every computation, piece of data should have a **formal type**.

Types permit (automatic) **checking** before **building**.



*Doing software without types is like doing **biology** without a post-Linnaean **taxonomy** ...*

*Beware:* most of the software running today is (still) **untyped** or too **weakly typed** (!)

## Parametricity and scalability

We also learned to appreciate **generic** (parametric) programs which automatically **instantiate** to specific needs.

**Polymorphic types do this** - nice theory called **parametric polymorphism** (John Reynolds, CMU).

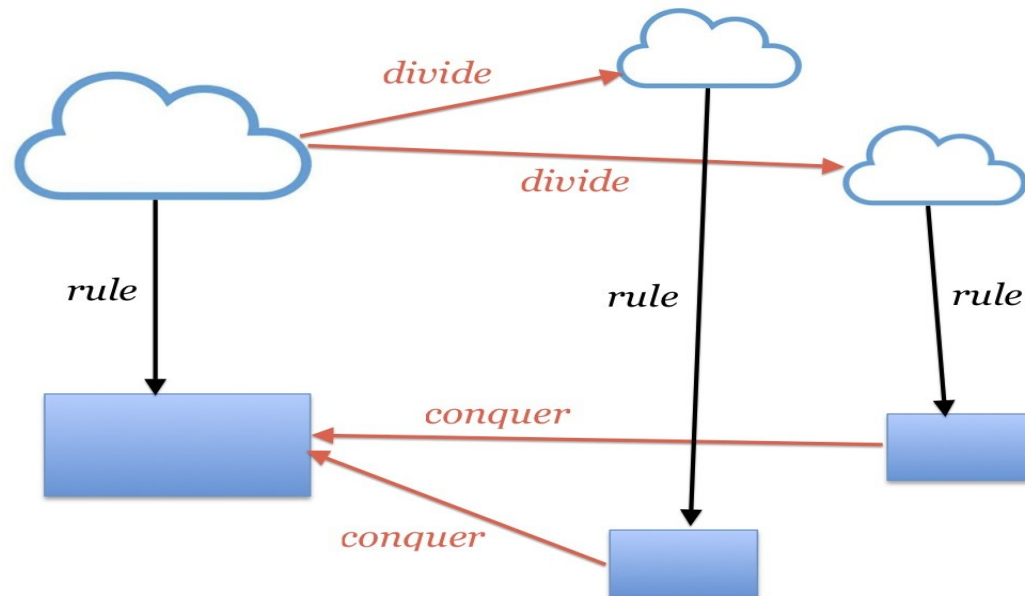
So nice that one derives **properties** of programs **before** even **writing them** — very helpful in **correctness** arguments.

Thanks to techniques like “lazy programming” our **generic** programs have also become **scalable**.



## Divide & conquer metaphor

We have learned to better understand and take advantage of this '*quinta essentia*' of programming.



Thanks to **D&C** our programs have become **parallel**. Think of **Google, cloud** computing, ...

# Cyber-security

Surely the **most critical** problem ahead.

**for some do** {*human* :=  
*intruder*}

We are learning how to use **number** theory and **automata** theory to build software that is **provably** secure.



## Contract-oriented programming

We have also learned that, as in the regular functioning of any **society**, programming should be based on **formal contracts** validated using the underlying **maths**.



Contracts ensure **safety** and **security** essential to **safety-critical** equipment operation.

## What can I4.0 learn from SE?

Level of **sophistication** and **safety** needed in **I4.0** incompatible with **ad hoc** software development.

**I4.0** should invest on **high-assurance**, **parametric** software **components** developed on a grand scale.



Opportunity for developing widely available, certified **cyber physical component** (CPC) libraries.