Industrie 4.0 - Advanced Engineering of Smart Products and Smart Production

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Abstract: ***Industrie 4.0 is a strategic approach for integrating advanced control systems with internet technology enabling communication between people, products and complex systems. The key approach is to equip future products and production systems with embedded systems as a basis for smart sensor and smart actuators for enabling communication and intelligent operation control. These so-called Cyber-Physical- Systems challenge design and development processes and require appropriate engineering approaches. Within this contribution the state–of-the-art for Industrie 4.0 is being presented, key use cases are reported and an approach for establishing Industrie 4.0 in industry is presented. In this context, a fundamental issue is to understand the role of integrated safety, security, privacy and knowledge protection.***

Keywords: Industrie 4.0, smart engineering, smart sensors, smart actuators, safety and security, multidisciplinary product development, mechatronics, adaptronics, cyber-physical systems

1. Introduction

Industrie 4.0 implies the 4th industrial revolution and is one of the German research initiatives to implement the German high-tech strategy 2020 [1] to meet the challenges of the 21st century. While the 1st industrial revolution is considered as the introduction of hydro power and steam power, the 2nd industrial revolution is understood as the introduction of mass-production techniques by using electric energy. The 3rd industrial revolution is based on the application of electronic systems and information technology for enhancing manufacturing automation. A significant breakthrough is now expected as the 4th industrial revolution by introducing so-called cyber-physical systems (see figure 1) [2,3,4,5].

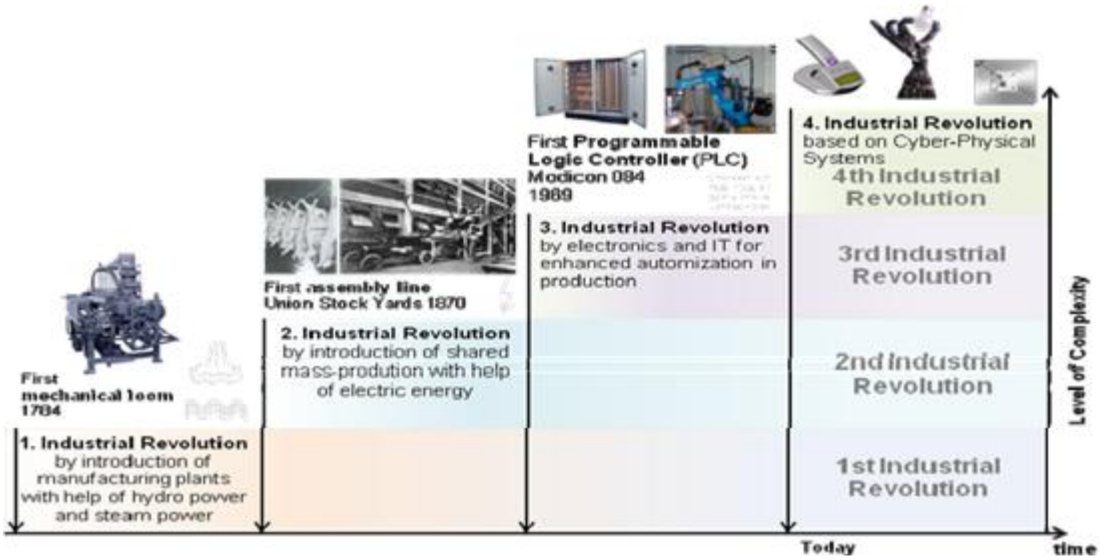

Figure 1: Industry 4.0 - The 4th industrial revolution (source: Zukunftsprojekt Industrie 4.0 [3])

The fundamental approach of Industrie 4.0 is using the ability of cyber-physical systems to provide intelligence and communication for artificial, technical systems which then are called smart systems. Smart systems may be understood as a consequent successor technology of mechatronic and adaptronic systems. The main feature is the integration of cyber-physical systems for enabling inter-system communication and self-controlled system operation. Smart systems are to be used for condition monitoring, structural health monitoring, remote diagnosis and remote control. They are a kernel component for smart products, smart factories, smart grids, smart logistics or even the smart city (see figure 2). The intension for introducing smart systems is the establishment of new value-added processes and new value-added networks to increase and to improve flexibility, adaptability and efficiency of businessprocesses.

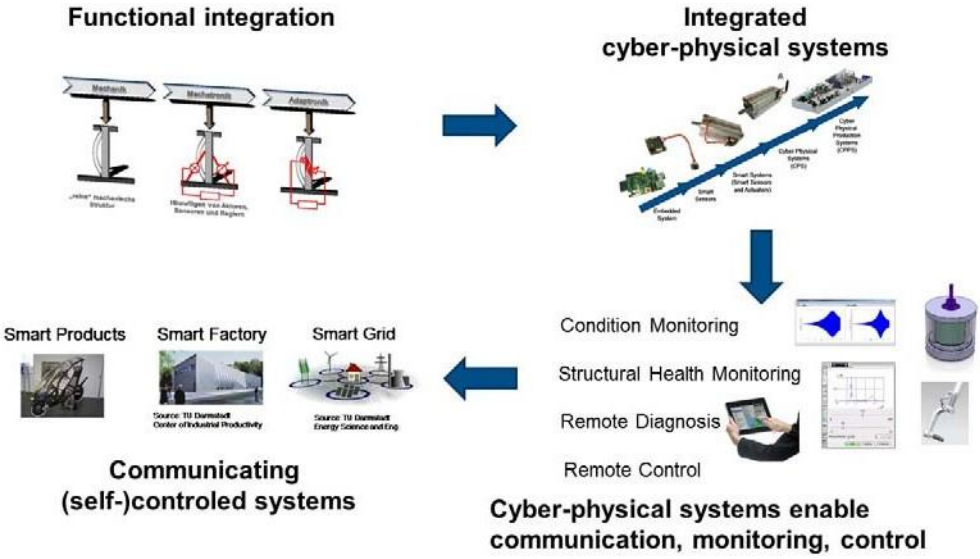

Figure 2: The smart system approach

Business processes based on smart systems will also open the gate to establish fundamentally new business models where the functionality of smart systems will be extended with integrated services. This new packaging of systems' functionality and services will enable new approaches to meet customer and market demands.

Within this contribution the approach of Industrie 4.0 will be explained and use case scenarios will be presented. Furthermore the approach of transferring Industrie 4.0 to the industry in Germany will be illustrated as well as some international activities to strengthen industrial competitiveness based on smart systems

Fundamental Approaches of Industrie 4.0Technology

Industrie 4.0 technology aims at enabling communicating, intelligent and self- controlled systems. From a technological point of view Industrie 4.0 is characterized by 4 fundamental conceptual approaches. They comprise:

- Cyber-physical systems,
- Internettechnology,
- Components as information carriersand
- Holistic safety and security including privacy and knowledge protection.

The combination of these conceptual approaches enable smart systems as a kernel feature of Industrie 4.0 applications.

1.1 Cyber-PhysicalSystems

The approach of cyber-physical systems has been described by LEE [6] as an intersection of the theory of computation and the theory of dynamic systems. This results in two complementary approaches called Cyberizing the physical:

Cyberizing the physical aims at specifying physical subsystems with computationals abstractions and interfaces. This also leads to equip physical subsystems with intelligence enabled e.g. through embedded systems.

Furthermore communication becomes an important feature to interact with both, other cyber-physical systems as well as humans.

Physicalizing the cyber: Physicalizing the cyber expresses abstractions of dynamic systems to software and interfaces as well as network components to represent their dynamic behavior in time.

Cyber-physical systems may be understood as a consequent configuration of embedded systems, sensors, actuators including network access. Figure 3 shows a configuration approach that enables the creation of cyber-physical systems and its further application as cyber-physical production systems.

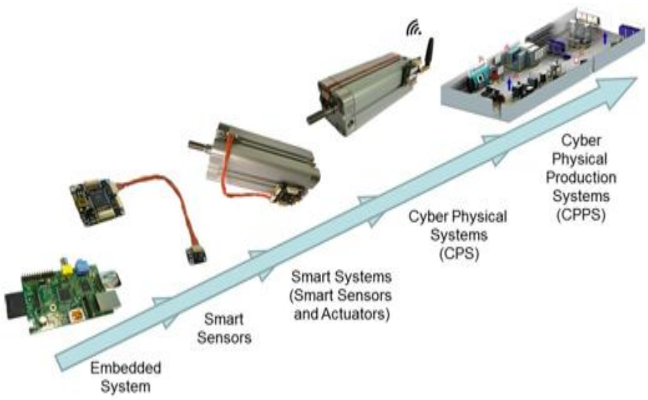

Figure 3: Cyber-physical systems

In cyber-physical systems network access can be provided in particular by equipping embedded systems with an internet protocol address (IP address).

- **Internet Technology:** Modern and future internet technology provides essential approaches to enhance the performance of cyber-physical systems. These internet technology approaches comprise 3 concepts:
- **The internet of things (IoT):** The internet of things comprises communicating smart systems using IP addresses. The upcoming IPv6 (internet protocol version 6) supports an IP address space of 128 bits which enables to define 2^128 individual addresses or 3.4*10^38 addresses. This enables each and every physical object being equipped with a unique IP-address.

- **The internet of services(IoS):** The internet of services comprises new service paradigms such as provided by the service oriented architecture (SOA) [11] or the REST-technology [8] .
- **The internet of data (IoD):** In an environment of the previously mentioned internet of things and internet of services technologies huge amount of data will be generated. The internet of data will enable to transfer and to store mass data appropriately and to provide new and innovative analysis methods to interpret mass data in the context of the target application.

Figure 4 illustrates the internet technology impact on cyber-physical systems.

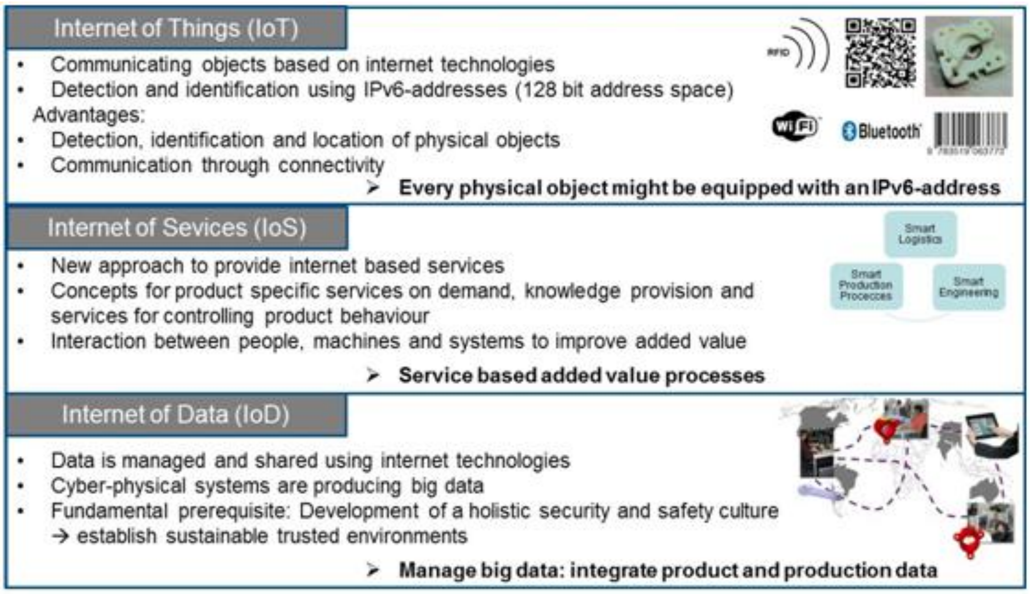

Figure 4: Impact of modern and future internet technology

As a consequence new industrial topics such as big data and could computing are gaining an increasing importance.

1.2 Manufacturing Objects as InformationCarriers

The approach of cyber-physical systems enables objects to be identified, localized and addressed. Assigned to manufacturing objects such as single parts and assemblies this technology opens new innovation paths. Manufacturing object become information carriers as well as connected objects in a network of communicating instances. Manufacturing history assigned to manufacturing objectscreate individual object information which is essential for successive manufacturing processes and backtracing analysis.

Furthermore manufacturing objects are connected to product model structures as well as process planning data and thus they are enabled to actively control their own manufacturing processes and procedures. Figure 5 illustrates an example of a manufacturing object, the bottom of a pneumatic cylinder. The bottom part is identified and by analyzing its product structure, its assembly is detected and through the assembly the assigned assembly plan, the assembly area as well as the appropriate counter parts are accessed. This scenario also shows how optimization for assembly processes issupported.

Figure 5: Manufacturing objects as information carriers

To support the concept of manufacturing objects becoming information carriers an appropriate specification of information attached to manufacturing objects is required. This requirement can be met by specifying a so-called component data model. The component data model is derived from the product data model approach as available through the STEP standard (Standard for the Exchange of Product Model Data, ISO 10303 "Product Data Representation and Exchange [7]).

1.3 Holistic Approach for Safety, Security, Privacy and Knowledge Protection

Cyber-physical systems equipped with internet technology (IoT, IoS and IoD) require outstanding concepts and technologies for to ensure safety, security, privacy and knowledge protection. These concepts have to be applied in a real-time environment which typically addresses manufacturing environments. Figure 6 compares issues of the office oriented environments with those issues typically addressed by manufacturing environments.

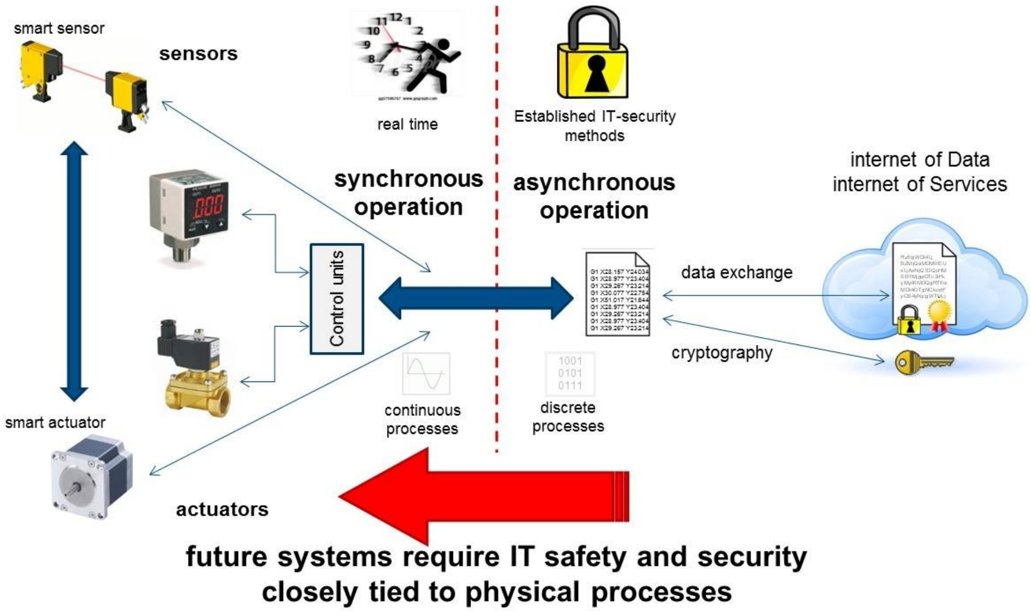

Figure 6: Synchronous versus asynchronous application environments [9]

Safety requirements address the continuously available manufacturing operation ability while security aims at the resilience against external and internal attacks against the cyber-physical environment.

Privacy ensures the execution of operational functions without being monitored to a third instance. Furthermore knowledge protection provides methods and tools to avoid access to manufacturing knowledge from outside or from non-authorized instances.

Clearly, Industrie 4.0 concepts require IT safety and security to be tied closely to physical manufacturing processes also meeting real-time requirements.

3. Use Case Scenarios

Industrie 4.0 is expected to change the industry significantly. One of major changes is to further develop process management which today is strongly depending on centralized methods to more de-centralized but interlinked methods. Planning and control of processes will become much more flexible, adaptable and resilient against disruption. Some use case scenarios illustrate expectedbenefits.

3.1 Use Case 1 "Component as an Information Carrier"

Provided that components as manufacturing objects are identifiable or even addressable their current status will be registered individually. Use case 1 addresses manufacturing failures and its effect analysis. After having manufactured the bottom of the pneumatic cylinder the part is checked and verified against product design data in particular its dimensions and tolerances. The measurement indicates dimensions not meeting tolerance requirements (see figure7).

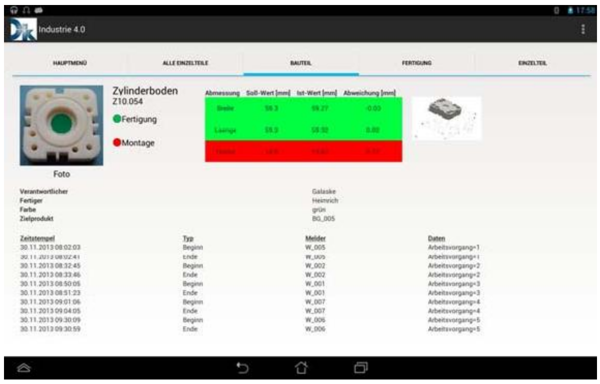

Figure 7: Checking and verifying manufactured parts

As a consequence the reasons why tolerances are not met have to be detected. Therefore effect analysis is appropriate and in this case the manufacturing plan indicates which manufacturing process is responsible for the failure. Through the manufacturing process the machine tool and the operation tool are identified and their conditions are being analyzed (see figure8).

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Figure 8: Manufacturing plan and monitoring of the operation tool

In this use case it becomes evident that the operation tool (red curve in the right picture of figure 8) approaches the end of its lifetime.

3.2 Use Case 2 “Process and Condition Monitoring”

Process and condition monitoring is one of the most important use cases. As products or components of products are based on cyber-physical systems their smart sensors are able to deliver data about the products’ or the components’ condition. Such data might be e.g. temperature, strain or vibration. The analysis and assessment of the data streams deliver information about the products’ or components’ condition. Consequently process monitoring methods can be supplied with information indicating the process stability or instability [10]. Actions to ensure process stability such as load balancing and predictive maintenance can be taken. Figure 9 illustrates process monitoring in a manufacturing environment.

Figure 9: Process monitoring in a manufacturing environment

While this use case has a high impact on the efficiency of respective value-added processes, this use case also underlines the high importance of analyzing promptly data streams produced by smart sensors. This is considered as an area where significant development of new innovation is expected.

3.3 Use Case 3 “Additive Manufacturing”

A very promising use case comprises additive manufacturing. This upcoming technology uses 3D-CAD data to drive a layer by layer manufacturing process. Data representing a spare part is delivered from a 3D-CAD system and is exported either as a STEP file or a STL file. This description of the parts’ geometry is used to compute ordered slices of the parts’ geometry. For each of these slices the tool path is generated and used to control the tool operation to produce the part layer by layer (see figure 10).

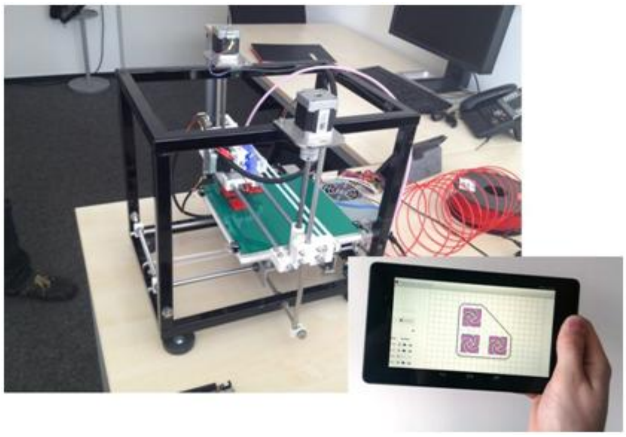

Figure 10: Additive manufacturing based on fused deposition manufacturing

The attractiveness of this use case results from locating additive manufacturing centers in the main markets worldwide and controlling the production by sending manufacturing control data to the appropriate additive manufacturing unit. Equipped with cyber-physical systems the additive manufacturing unit will report back about the successful production or in case of any problems also reports will be sent back. This scenario is in particular of interest for producing spare parts (figure 11).

Figure 11: Use case "Additive Manufacturing"

Furthermore also statistical data could be reported back indicating the frequency of produced parts in the various market worldwide.

4. Transfering Industrie 4.0 to Industry

Industrie 4.0 an important research initiative to implement the German high-tech strategy. A report about the transfer of the conceptual approach of Industrie 4.0 to German industry has been delivered to the German government in spring 2013. Industry itself has taken action to drive the implementation of Industrie 4.0. The main activity is the establishment of the so-called Platform Industrie 4.0 under the organizational auspices of 3 industrial associations BITKOM (ICT industry), VDMA (mechanical and process industry) and ZVEI (electrical and automation industry). Figure 12 shows the organizational structure of the Plattform Industrie 4.0.

Figure 12: Plattform Industrie 4.0 [14]

A major approach is the collaboration between industry and the scientific community through the initiation of a scientific advisory board. An important contribution of the scientific advisory board was the definition of 17 theses explaining the main features of Industrie 4.0 (see figure 13).

Figure 13: Theses of the scientific advisory board of the Plattform Industrie 4.0 [15]

In the meantime a research roadmap has been published and a number of research projects have been initiated to contribute to the Industrie 4.0 technology. Furthermore a couple of demonstration centers for Industrie 4.0 have been established (figure 14).

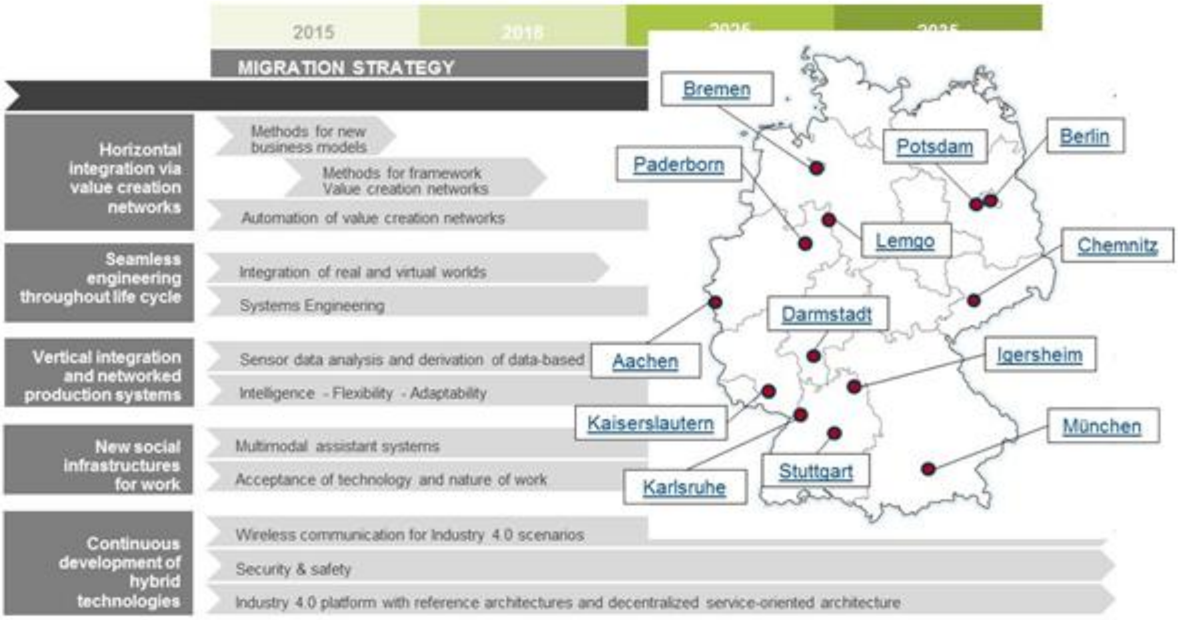

Figure 14: Research roadmap and demonstration centers for Industrie 4.0 [14]

Industrie 4.0 has created awareness in both, German industry and academia. The technology development, however, has also been started internationally. The European Commission has published a research initiative on advanced manufacturing [12], in the United States the Industrial Internet Consortium [13] has been established and further initiatives have been started in China, South Korea and Japan. This confirms the strong movement to make the Internet of Things, the Internet of Services and the Internet of Data areality.

5. Summary

Industrie 4.0 has become an important initiative for German industry. It is of strategic importance and aims at strengthening industrial competitiveness. The main features driving Industrie 4.0 are the development of cyber-physical systems, the integration of the internet of things, the internet of services and the internet of data technology, the understanding of components being information carriers and the implementation of a holistic approach to ensure safety, security, privacy and knowledgeprotection.

The main target is to improve the value-added processes and to develop new business models for strengthening industrial competitiveness. Future research activities will focus on smart systems development, vertical and horizontal process integration and seamless digital integration of lifecycle phases.

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