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SCIENTIFIC REPORT

TECHNOLOGY TREND REPORT

Industrie 4.0 and Essential Technologies as Seen from Academic Citations

A Breakdown Using Reference Data

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Our lifestyles have been dramatically altered by the development and popularization of ICT advances such as the internet, cloud environments, and high-speed wireless communications technology. We are able to look up information, access company data, and remotely control appliances, such as air conditioners and lights, from devices anywhere, via the internet. We can also automatically record and analyze our vital information, allowing for better health management. Through the further application of big data and the IoT, we will see an era in which predictive analytics are being increasingly applied to numerous fields.

The impacts of technological innovation using ICT do not only affect individuals but also extend to the business world. One of these is Industrie 4.0—promoted mainly in Germany—which aims to upgrade the manufacturing industry using the internet.

One goal of Industrie 4.0 is to create more sophisticated production systems, not only within individual companies but also with a focus on connections with outside entities. Another goal is for computers to aid in the advanced control of production processes. The significance here is in standardization and a reduced reliance on people. However, this does not mean that individuals will be eliminated from production sites. According to SAP, workers will be able to engage in more highly specialized jobs, with high levels of added value, and to gain knowledge and skills in a variety of fields.

Although it will have an impact on the manufacturing industry, we wonder what kind of essential technologies are associated with Industrie 4.0. There is also the question of what kind of industries will relate to these essential technologies. Therefore, we conducted an analysis of the essential technologies that contribute to Industrie 4.0, using academic citation data as a resource.

First coined around 2011, the term “Industrie 4.0” has a limited history, so it is difficult to grasp the complete picture of Industrie 4.0 by only looking at articles that mention this term. Thus, we gathered three layers of citation data from article titles, abstracts, and keywords: First, we focused on articles that included the terms “Industry 4.0” or “Industrie 4.0” (as source articles). Second, we used the articles that these source articles cited (as primary sources) and third, we included the articles that these primary sources cited (as secondary sources). We use Scopus—operated by the publisher Elsevier—to gather this data. Due to how we acquired our data, our reference citations were limited to the data recorded in Scopus. As the Industrie 4.0 concept is new, there were only roughly 5,800 relevant articles.

Macro Trends in Industrie 4.0 Research

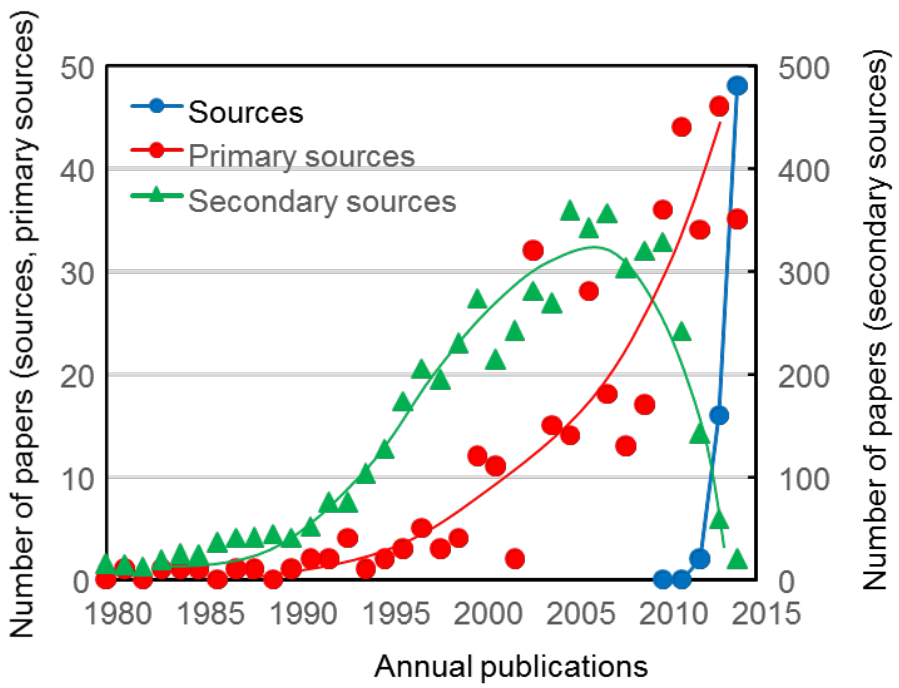

Figure 1 - Number of Industrie 4.0-Related Articles
(The solid lines on the graph are for ease of visibility.)

Figure 1 shows the number of research papers on Industrie 4.0 published over time. The scale for source articles and primary sources is on the left axis, while that for secondary sources is shown on the right.

As mentioned above, the term “Industrie 4.0” was first coined in 2011. Looking at academic citations, source articles first appeared in 2012, rapidly increasing thereafter. Meanwhile, primary sources first showed up around 1995, and secondary sources, around 1990. From a very broad perspective, it appears that the core research related to Industrie 4.0 began in 1990.

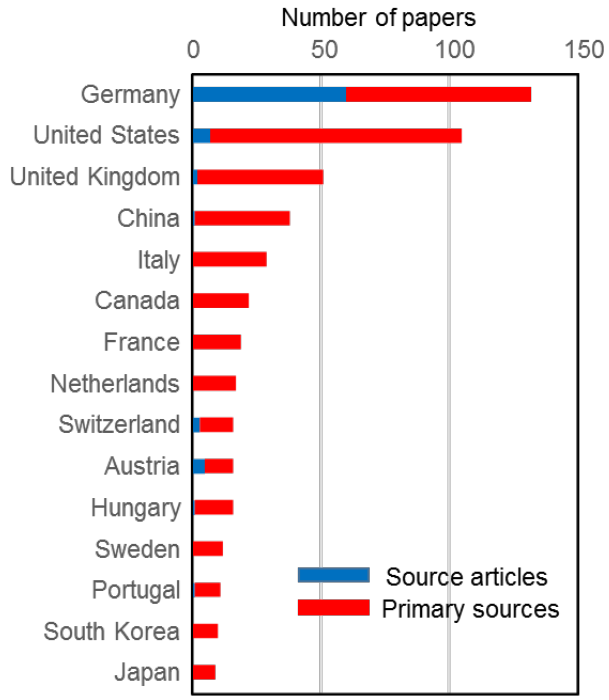

Figure 2 - Key Countries in Industrie 4.0-Related Research

Figure 2 exhibits the number of articles (source articles and primary sources) from the main research institutes in Industrie 4.0-related research for each country.

As the country that proposed the term, Germany has an overwhelming lead in the number of source articles published, followed by the US, Austria, and others. From the perspective of primary sources, the US has the most, outpacing Germany. These two are followed by the UK, China, and Italy in the top ranks. Although the chart does not show secondary sources, the US publishes far more of these publications than any other country, followed, in order, by the UK, Germany, and Canada. Japan is in 15th place for primary sources and 10th for secondary sources in relevant fields, demonstrating its lag behind the West in this research.

PANORAMIC VIEW ANALYSIS

Cluster Analysis of Related Articles

In order to clarify how broad the research related to Industrie 4.0 is in scope and in the different focal regions in each country, we performed a cluster analysis of the academic citation data that we gathered. We used tf–idf values to evaluate the feature quantity of documents gathered for our cluster analysis, which provides a visualization of this data, based on the degree of similarity among documents. We used the titles and abstracts of gathered articles to evaluate their degree of similarity. The results of this analysis are shown in Figure 3. The dashed blue lines in the chart are meant to make it easier to distinguish among the major technology regions.

Our cluster analysis results are broadly divided **into research fields related to production processes; networks and communications; web and mobile services, and related fields; and industrial alliances, such as those found in supply chains**.

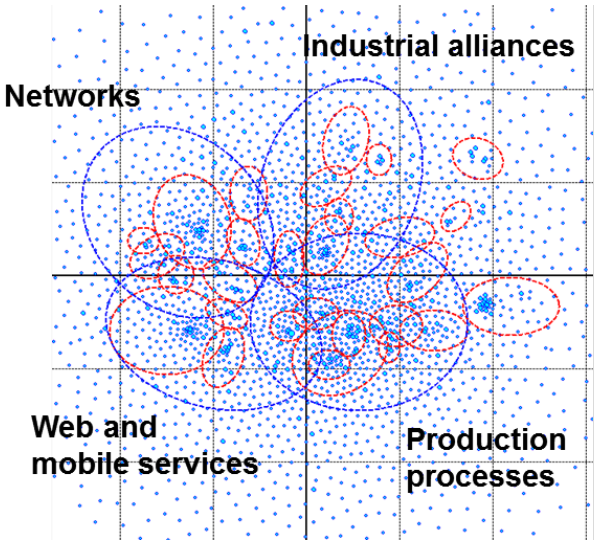

Figure 3 - Cluster Analysis Results for Relevant Articles

Looking at the more detailed results of our cluster analysis, several densely populated regions are taking shape. Figure 4 shows the names we assigned to the key cluster regions.

The production processes region consists of research fields such as job or production scheduling, holonic manufacturing, and multiagent applications. Also, a region for virtual companies has formed in the border area between the regions for web and mobile services.

In this latter region, much of the emergent research is related to **web services models and context awareness**.

The networking region includes research fields pertaining to **wireless networking, as well as to hardware, such as RFID tags and IoT devices**. Furthermore, we find wireless networking, which is connected to social networks, including mobile communication. The industrial alliances region contains research concerning product lifecycle design, supply chain management, and production efficiency. On the edges of these major technology regions, we see clusters for research fields such as fault diagnosis, design for assembly, and—slightly apart from the rest—problems with vehicle dispatching.

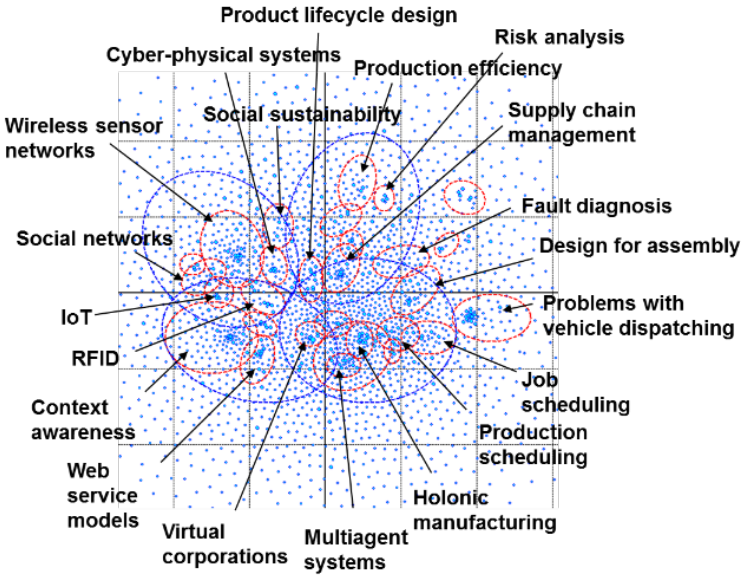

Figure 4 - Names Assigned to the Key Cluster Regions

The cluster analysis in this report includes the source articles, primary sources, and secondary sources that we collected. Figure 5 clearly shows where each of these types of articles appears in our cluster analysis results. This color contour chart shows the

number of articles per area, using changes in colors. Red indicates regions with a high density of articles (where research is concentrated), while blue indicates sparsely populated areas.

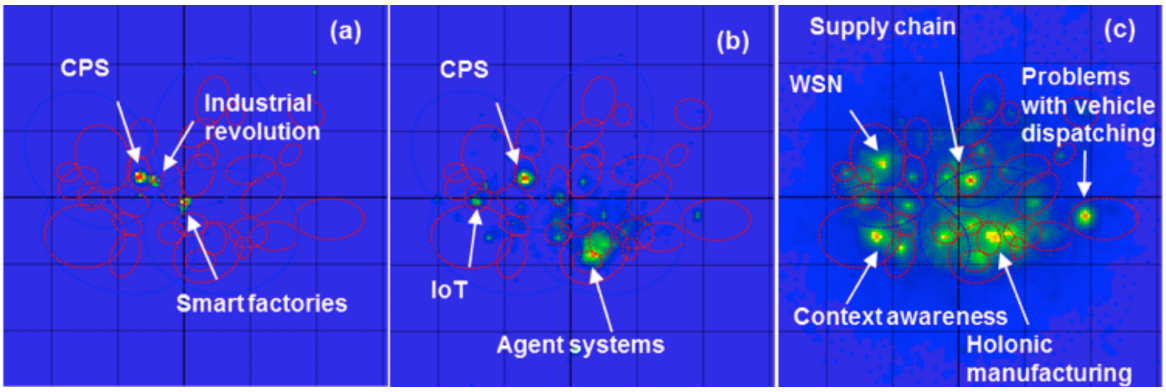

Figure 5 - Different Research Fields by Type of Article (a) Source articles, (b) primary sources, and (c) secondary sources

Looking at the source articles, there is a relatively **high concentration of articles near the center of the chart, in the region represented by the keyword "industrial revolution" and in the regions for smart factories and cyber-physical systems** (CPS). The region that includes the "industrial revolution" keyword has many articles describing the Industrie 4.0 concept. "Smart factories" can be considered the main production-focused efforts being undertaken for Industrie 4.0. CPS serves the primary role of control in Industrie 4.0, providing controls that link virtual space with real space.

From the perspective of primary sources—the articles cited by these source articles—**the regions with the most concentrated research are CPS, IoT, and agent systems for manufacturing**. IoT refers to connecting devices to each other via the internet, and it is the concept that originally sparked the idea of Industrie 4.0. Agent systems research is concerned with the formulation of production plans and multiagent applications in domains such as negotiation and assembly cell control.

Compared to the Industrie 4.0 source articles and the primary sources cited by these articles, the secondary sources cover a much broader spectrum of topics. **Regions with significant concentrations of research include topics such as wireless sensor networks (WSN), supply chain management, context awareness, and multiagent systems**. However, there is a wide range of other topics in these articles, including virtual companies, RFID, and problems with vehicle dispatching.

Main Regions by Country

Germany is leading the promotion of Industrie 4.0, but we wondered what essential technologies key countries are focused on. Figure 6 is a color contour chart that shows the research fields for the top five countries in terms of total articles.

Germany

Germany's main research fields are mostly found in the regions near the center of the cluster analysis results. Specifically, we find concentrations of research related to **industrial automation and to CPS**. There are also concentrations of research on supply chain management (SCM). On the other hand, we do not find concentrations in the WSN research field. Another characteristic of German research is the large volume of support vector machine-related research.

The USA

The US has an exceptionally large number of secondary source articles. The research fields cover all regions of the cluster analysis, but there are particularly large volumes of research in **wireless sensor networks, CPS, and RFID**. These technologies are applicable in domains not limited to only Industrie 4.0. We also find a wide range of articles in SCM and industrial applications for multiagent systems.

The UK

Much of the UK's research is in topics such as **virtual companies, SCM, scheduling, and multiagent systems**. There is not much research in regions for sensor networks and context awareness.

Canada

Canada has a notable presence in research clusters for **production controls and problems with vehicle dispatching**.

Italy

Italy conducts research all over the chart, covering WSN and production support tools, as well as problems with vehicle dispatching.

As above, there are differences in the research fields among the key countries. The differences in core research fields between the US and Germany—the country that proposed the concept and that has a significant lead in the number of related articles published—could be said to represent a **complementary relationship**.

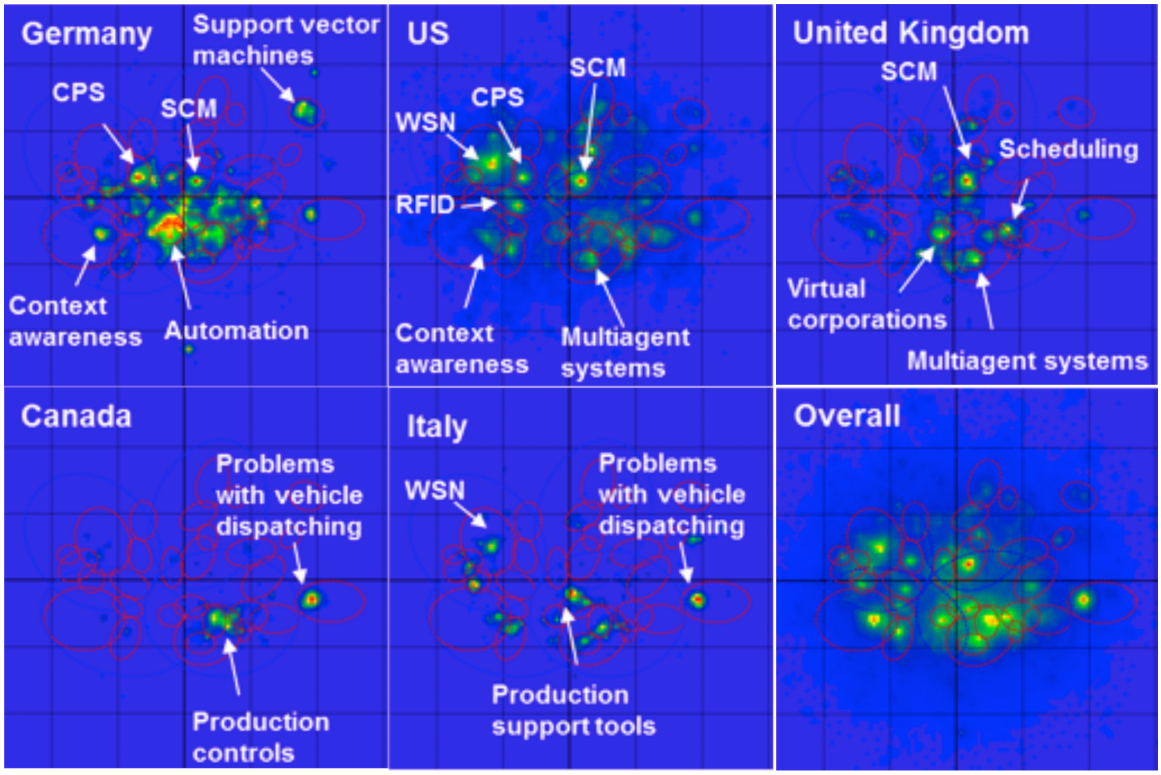

Figure 6 - Research Fields for the Key Countries

Trends in Related Research Seen in Cited Articles

Articles mentioning Industrie 4.0 began to appear in 2012, and there are not so many of these articles. Therefore, it is difficult to see trends just using these articles. We sought an understanding of the shifts in researchers' interests by asking how the articles cited from 2013 to 2015 had changed. The results of this analysis are shown in Figure 7.

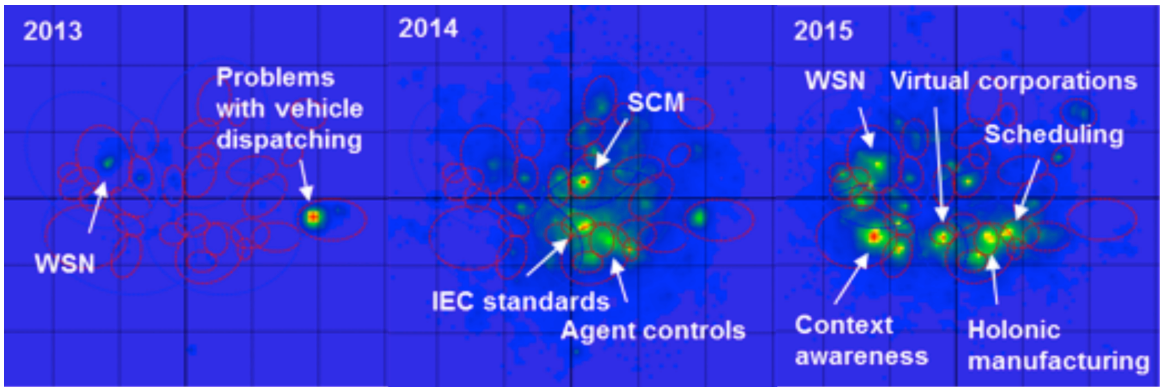

Figure 7 - Changes in Researchers' Fields of Interest as Seen by Cited Articles

Per the shifts in articles cited, the primary sources and secondary sources for the source articles published in 2013 were mostly concerned with problems of vehicle dispatching, followed by articles on wireless sensor networks. (There were not many other articles published.) In 2014, research related to supply chain management, agent controls, and IEC standards become active. IEC standards refer to the international standards for electrical and electronic fields, and we find research related to IEC standards on topics such as distributive systems.

There was a further change in the fields with articles cited in 2015, with regions primarily on the left side of the cluster analysis chart becoming active. Specifically, many articles were cited regarding networking technologies such as wireless sensor networks, software technologies such as context awareness, and virtual companies. In addition, there were increases in the production processes region, in scheduling and holonic manufacturing.

These changes in the research fields of cited articles could indicate a more practical and specialized focus in Industrie 4.0.

Participation by Private Companies

We wondered how private companies are participating in research related to Industrie 4.0. Based on the author information of academic citations, we created a visualization of the efforts of private companies, shown in Figure 8. In this figure, the areas surrounding clusters of articles that included private companies as the authors' affiliated institutions are marked in red.

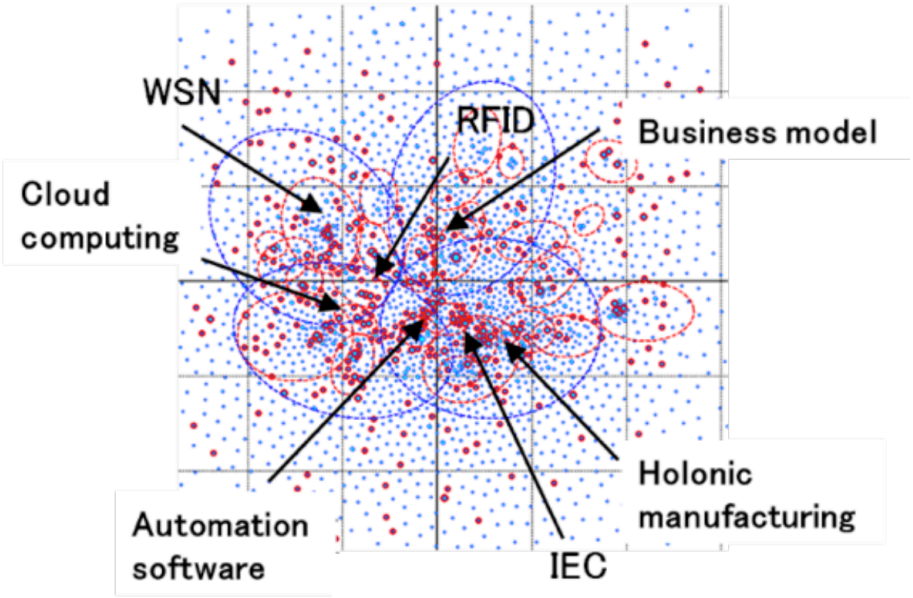

Figure 8 – Participation by Private Companies

As seen in the cluster analysis results, the efforts of private companies span the entire spectrum of research. By region, the production processes region has much research related to IEC standards, automation, and holonic manufacturing, while it does not contain much research on agent controls. The web and mobile services region has a great deal of research on the cloud, but research on context awareness is limited to a part of the region. In terms of networking research, we find concentrations in the areas for RFID and sensor networks, but not much in CPS. The region for industrial alliances includes research related to business models, but regions for supply chain management or production efficiency do not have much research.

Because all private company efforts will not necessarily appear in the form of academic citations, there is a risk to making a determination based on only these results. However, **among the technologies thought to be necessary for Industrie 4.0, it is likely that several technology regions do not have sufficient research from private companies. If we consider Industrie 4.0 to be a business opportunity, these regions could be openings to new markets**.

CONCLUSION

We conducted an analysis of research and development trends related to Industrie 4.0, using cluster analyses based on academic citation data.

Industrie 4.0 covers research topics such as advanced production process management, using multiagents that include scheduling and diagnostic features; integrated cyber-physical systems; sensor networks and RFID technologies meant to gather data; and context-aware software for processing this data. The cloud environments for processing these tasks are also related to Industrie 4.0. Furthermore, various related elements arise, including virtual companies for processing virtual transactions and supply-chain management systems. In addition, although not covered in this report, security is also a vital element in Industrie 4.0. Additionally, security-related research is broadly distributed in regions such as networking and web and mobile services on the cluster analysis charts.

The stated goal of Industrie 4.0 is to optimize entire industries, not just individual companies. However, even if this goal is not achieved, **Industrie 4.0 has the potential to produce technologies that could change the future of manufacturing**. This is likely to produce technologies that contribute to mass customization and holonic manufacturing, which are expected to develop further, as well as production process optimizations that Japanese companies are already working on. We should continue to focus on Industrie 4.0-related trends, and Japanese companies, too, need to promote related initiatives.

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