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Bibliometric Analysis of a Comprehensive of Culture and Symbol in Character Animation during (2004–2024)

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Abstract

The analysis of academic research on animated characters in the animation industry effectively summarises the current state of scholarly research on animated characters through a variety of software tools such as CiteSpace, VOS viewer, HistCite, and Bibliometrix analysis, and visually charts and formulates this data. Through study and research, it that the United States is (278) the most prolific country, and the United States has the highest intermediary centrality, as well as the most Centre National de la Recherche Scientifique (CNRS) and PEOPLES R CHINA are the most cited organizations and Countries/Regions with the highest intermediary centrality and Countries/Regions with the highest citation explosiveness, respectively. This study also suggests possible challenges and future directions in character design for animated characters.

Keywords: *Animation Characters, Software, Bibliometric Analysis, Visualization.*

Introduction

The animation industry is driven by the advancement and development of animation research, and scientific research results related to animation characters are continually increasing! This is due to the updating and developing of science and technology, artificial intelligence, AI generation, meta-universe XR technology, CAD technology, chat GPT, web3.0 technology, and other new technologies that serve as the cornerstone for the output of technological achievements (Lan et al., 2023; Liu & Yao, 2023). A distinct animation style emerged due to an increasing number of animation makers concentrating on animation characters to draw in more viewers and consumers of animation-related merchandise. The growth of the animation economic sector is driven by character design, and this is an unavoidable tendency in the field's present development (Giesen & Khan, 2017). The discipline of animated characters has received increased attention from academia and governmental departments as the related technology has been further developed, and as a result, there is a wealth of achievements in animated character development and research.

In the animation industry, academic achievements are primarily seen in character design and development. Some academics believe businesses should work more closely with scientific research organizations to enhance industry-academia research collaboration (Bao et al., 2024).1 Design Concept: Researchers focus on organically combining the character's personality, appearance, behavior, and other characteristics to make it a natural and believable existence, reflecting the story background, plot development, character's inner world and other elements.2-Focused Direction: Researchers explore how to implement the character design concept into every step of the game development to make the character's design more complete, realistic, engaging, and better reflect the design concept, realistic, exciting and better reflect the design concept. At the same time, they are also exploring how to create a benign interaction of "content-image" in animation character design to grasp the overall style of the character in the game.3 Digitization of design: Researchers are exploring how to integrate animation character design into 3D and digital post-production to better transform the concept of animation character design into a visual image. Visual image. They are also studying how to utilize new technologies for character design, such as artificial intelligence, virtual

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reality, augmented reality, etc., to enhance the animation character and make the animation works further realize a perfect perceptible world.

The existing academic research on animation characters' character design concepts focuses more on the direction and design of digitalization. At the same time, many have been openly published in publications, so for the academic community to provide the latest research results of the dynamics of the enterprise to provide the latest animation character theory on the summary of the existing research data is indispensable.

In order to better understand the changes in animation character research and the latest research dynamics in this field, on the one hand, building on the information obtained from the search of literature research to understand the hot issues in this research field, exploring the literature with time segments from 2004 to January 2024 and giving a comprehensive summary of the discussion. On the other hand, this article will be visualized and described intuitively through bibliometric analysis, showing the development of this research and future evolutionary trends; this thesis contributes to the research in this field as follows:

- The performance analysis of related publications is carried out, describing the essential characteristics of the publications in terms of annual quantitative indicators, areas of research, and literature cited with high frequency;

- Identify authors and influential literature as well as highly productive institutions and delve into institution-to-institution, author-to-author, and author-institution partnerships;

- Publication references are analyzed, institutions, authors, and countries/regions, and research frontiers are presented through a timeline;

- Keywords are used to identify frontiers and trends, research themes, and possible future hotspots;
- An in-depth discussion from the perspective of current hotspots, future prospects, and limitations.

This thesis is divided into chapters, as shown in Figure 1, and the rest of the paper is as follows: firstly, the research methodology of this thesis is presented in Chapter 2, including the data sources, the construction of the retrieval formula, and the bibliometric methodology. The four aspects of basic statistical features are described in detail in Chapter 3, and the results are presented. Then, Chapter 4 provides a more in-depth discussion from multiple perspectives of current topical issues, future trends in development and evolution, challenges that may be encountered, and limitations of this thesis. The final chapter of this paper, Section 5, summarizes the paper.

Methods

In this paper, the literature is visualized in software utilizing econometric analysis. At the outset, relevant publications were searched in the database. Then, the essential characteristics of the literature resulting from the public search were described in terms of the number of papers published per year, research direction, highly cited papers, and type of publication. Next, the authors, institutions, countries/regions, and their collaborations with significant influence in various aspects of the research field were identified through the available bibliometric approaches and metrological tools. Further, the latest directions of research frontiers in the field, current hot spots, and possible future trends are identified. It concludes with a discussion and summary. Referring to Figure 1, the framework of this study is listed.

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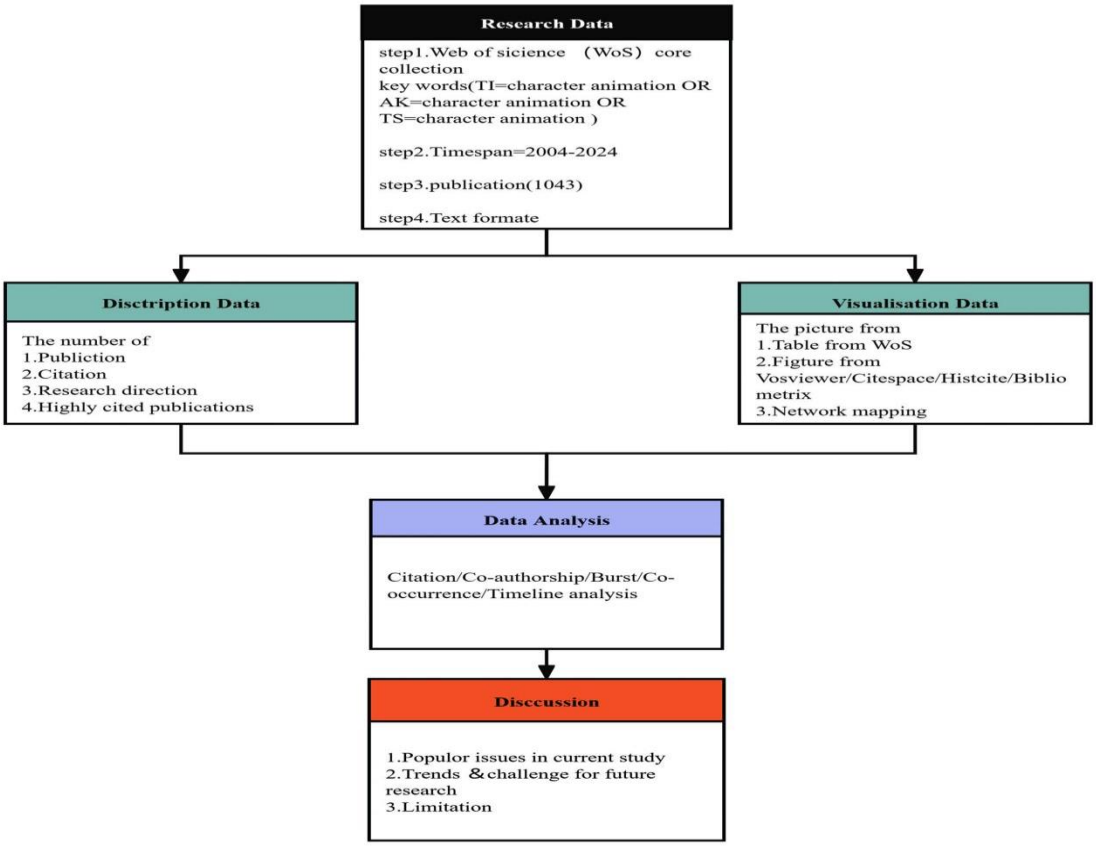

Fig. 1. The Research Framework of the Methodology.

Database Selection and Retrieval Strategy

The Web of Science (WoS) is the world's most authoritative, longest-running, and widely used research publications and citations database. Based on the Science Citation Index, founded by Eugene Garfield in 1964, it has expanded to provide complete coverage, balance, and selectivity of the world's leading research, until recently containing some 34,000 different journals (Qiu & Lv, 2014). Currently, WoS is widely used in all types of academic research (Singh et al., 2021), and over time has evolved to become the database of choice for scholars to conduct bibliometric analyses of their research (Birkle et al., 2020).

In this paper, a search was conducted in the Web of Science core ensemble database, and by constructing a search formula search, the number of open publications in the field of animation character research was 1,145 as of January 14, 2024. Selecting the literature spanning 2004-2024 for further refinement, we obtained 1,043 articles and then exported the information related to the search results in plain text. Table 1 shows a detailed description of the query during the retrieval process.

Table 1. Query description.

Category	Limitation	No. of refined documents
Query outcomes before search refine (((TI=(Character animation) OR AK=(Character animation) OR TS=(Character animation)))	Character Animation	1145
Time span (2004-2024)		1043

Source: Author.

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Bibliometric Methods

As a scientific method of analyzing data, bibliometrics is very popular in various disciplines and covers the dynamics of research in various fields. In recent years, bibliometrics has had many applications in analyzing literature in various majors (Zupic & Čater, 2015).

Scientific research is an increasingly collaborative endeavor. Differences in disciplines can lead to changes in the nature and scale of collaboration, depending on the nature of the research problem, the research environment, and other factors. Early studies have shown a high correlation between collaboration and financial research support, as well as a high correlation between collaboration and research productivity. The extent of collaboration cannot be readily determined by traditional surveys and observational methods (Thelwall et al., 2023). Bibliometric methods provide a convenient and non-reactive tool for studying research collaboration. This paper identifies several types of collaboration and reviews earlier research on collaboration. Collaborative research between scholars and disciplines can be represented. It has a solid scientific and reference value (Subramanyam, 1983).

This paper uses performance analysis in technical bibliometrics and scientific mapping analysis to reveal the development of CHARACTER ACTIVATION research through the above two analytical methods. Specifically, performance analysis can present the performance of different research components in the field (e.g., authors, institutions, countries, and journals), and the performance analysis in this paper includes the number of retrieved papers (NP), the number of citations retrieved (NC), and the average number of citations retrieved per publication (AC) (Zhang et al., 2022). Scientific mapping focuses on the relationship between components; this analysis involves the intellectual interactions and structural links between the components of the study; in this paper, scientific mapping includes citation analysis, co-word analysis (co-word analysis), co-authorship analysis (co-authorship analysis), burst detection analysis and timeline analysis. Not only that, but this paper also used VOSviewer (Jeong & Koo, 2016; Yu et al., 2020), CiteSpace (Chen, 2016; Chen & Liu, 2020), Bibliometrics (Donthu et al., 2021), and HistCite software were used to process and analyze the data (Bornmann & Marx, 2012; Garfield & Pudovkin, 2004).

Results(Jeong & Koo, 2016)

Using the literature data obtained from the search and the tools and methods proposed for use, this chapter analyzes the essential characteristics of the literature obtained from the search in four main directions.

Performance Analysis

First, this subsection provides a preliminary literature analysis regarding the number of annual publications, types, research directions, and high-frequency citations.

Annual Number of Literature Publications and The Total Number of Publications in Different Countries

The number of published literature in 2022 is the highest, reaching 85 articles. 2020 and 2023, the total number of articles is the second, and the total number of annual publications is the same number of 62; figure 3 clearly shows that in the United States and China, each year, the amount of published articles is the most, the United States was the earliest to publish articles in 1998 and only the country, a total of 3 articles, indicating that the United States in animation character research published in but is the most leading. From 1998 to 2023, the United States published articles yearly, except in 2013, when China surpassed the United States. The United States has the most significant number of articles in 1998-2018, and as of January 2024, only China has published articles, while since 2019-2024, China's total number of articles per year is the largest in terms of a single country. The total number of articles published in 2022 is the highest, as high as 91 articles (USA 12, China 47, UK 7, South Korea 9, Canada 5; France 5, Japan 3, Switzerland 2, Spain 1). The overall trend of the number of articles per year is increasing, which indicates that the academic attention to animation characters is gradually increasing.

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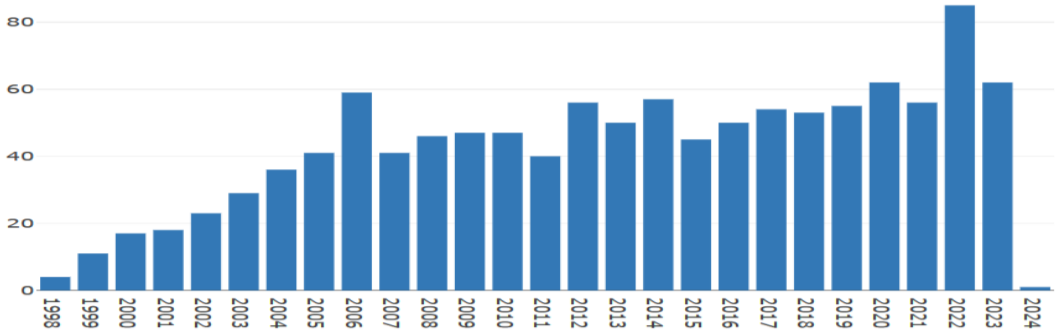

Fig. 2. Total data of literature published over the years

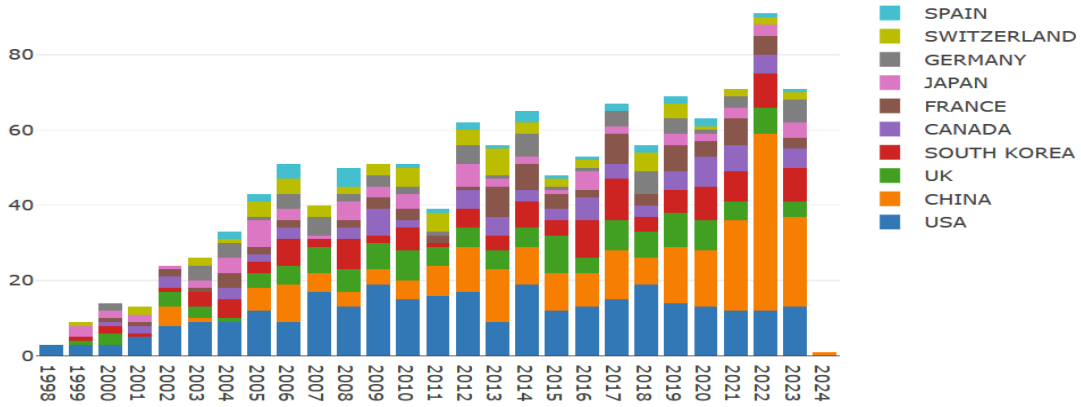

Fig. 3. Annual number of published articles change data

Types of Publications and Areas of Research

In this paper, the types of literature are filtered during the search process; at the same time, in the WOS database, all the literature is categorized into different types, and some types of literature will belong to two or more types at the same time, so there will be a situation that the number of literature corresponding to each type will be more than the number of retrieved literature.

In the Web of Science, each publication belongs to at least one research area, and the top 10 research areas selected in this section are shown in Figure 4; out of 1043 publications, Computer Science Software Engineering (729)69.856%, Computer Science Information Systems (93)8.995%, Computer Science Artificial Intelligence (83)7.943%, Computer Science Theory Methods (72)6.986%, and Engineering Electrical Electronic (72)6.986%, Telecommunications (41)3.923%, Computer Science Interdisciplinary Applications (32)3.062%, Computer Science Cybernetics (26)2.488%, Neurosciences (18)1.722%, Multidisciplinary Sciences (17)1.627% , The number of citations is average is 21.76, The total number of citations is 22,759, the Remove self-citation is19,151.

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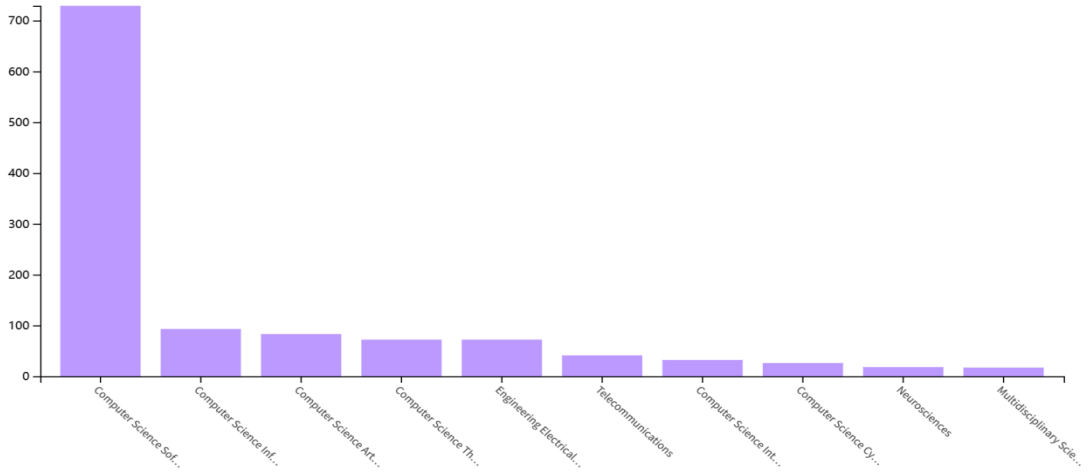

Fig. 4. The top 10 research areas

Highly Cited Publications

Excellent academic research publications may have a high chance of becoming highly cited because they are known to the public for their outstanding experimental design, rigorous logical deduction, or groundbreaking discovery. The higher the number of highly cited papers, the greater the recognition of the researcher's ability and the greater the indication of the scholarly value of the cited literature and its impact on other academic research (Thelwall et al., 2023) . Therefore, citation analysis indicates whether a piece of literature has a high impact. Table 3 compiles the ten most highly cited animated character literature from 2004-2024. Table 2 provides detailed information. The most highly cited literature is Robert W. Sumner and Popovic, Jovan, published in ACM TRANSACTIONS ON GRAPHICS, with 610 citations. In contrast, the highly cited literature was published between 2020 and 2024.

Table 2 Top 10 Cited Paper in the list

Rank	Paper Title	Journal Title	Document category	YP	NC	AC	AN
1	Deformation transfer for triangle meshes	ACM TRANSACTIONS ON GRAPHICS	Article; Proceedings Paper	2004	610	29.05	2
2	Style-based inverse kinematics	ACM TRANSACTIONS ON GRAPHICS	Article; Proceedings Paper	2004	387	18.43	3
3	Automatic rigging and animation of 3D characters	ACM TRANSACTIONS ON GRAPHICS	Article; Proceedings Paper	2007	323	17.94	2
4	Being with virtual others:	NEUROPSYCHOLOGIA	Article	2006	320	16.84	7

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	Neural correlates of social interaction						
5	A Deep Learning Framework for Character Motion Synthesis and Editing	ACM TRANSACTIONS ON GRAPHICS	Article; Proceedings Paper	2016	312	34.67	3
6	DeepLoco: Dynamic Locomotion Skills Using Hierarchical Deep Reinforcement Learning	ACM TRANSACTIONS ON GRAPHICS	Article	2017	296	37	4
7	Phase-Functioned Neural Networks for Character Control	ACM TRANSACTIONS ON GRAPHICS	Article	2017	280	35	3
8	Discovery of Complex Behaviors through Contact-Invariant Optimization	ACM TRANSACTIONS ON GRAPHICS	Article	2012	280	21.54	3
9	A material point method for snow simulation	ACM TRANSACTIONS ON GRAPHICS	Article	2013	241	20.08	5
10	A Statistical Model of Human Pose and Body Shape	COMPUTER GRAPHICS FORUM	Article	2009	223	13.94	5

* YP : Year of publication; AN: the number of authors; NC : Number of citations ; AC : The average number of citations per year

Table 3 lists the total number of citations, cited frequencies, and the average number of citations per publication for the top 10 most productive journals. We can find that the most prolific journal is ACM

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TRANSACTIONS ON GRAPHICS, with 249 relevant publications, and COMPUTER ANIMATION AND VIRTUAL WORLDS, with 120 COMPUTER ANIMATION AND VIRTUAL WORLDS, with 120 related documents, is ranked second.TECHNOVATION, despite having only 10 publications, has a citation frequency of 239, which is a lower citation frequency. ACM TRANSACTIONS ON GRAPHICS is cited by an average of 55-56 documents per publication, and with an SJR 2021 score of 2.22, the value of this journal is very high.

Table3 Top 10 most productive journals

Rank	Publication Titles	Number	NC	AC
1	ACM TRANSACTIONS ON GRAPHICS	249	13941	55.98
2	**COMPUTER ANIMATION AND VIRTUAL WORLDS**	120	853	15.18
3	**COMPUTER GRAPHICS FORUM**	100	1822	18.22
4	**VISUAL COMPUTER**	59	494	8.37
5	**IEEE TRANSACTIONS ON VISUALIZATION AND COMPUTER GRAPHICS**	52	919	17.67
6	**LECTURE NOTES IN COMPUTER SCIENCE**	37	133	3.59
7	**COMPUTERS GRAPHICS UK**	34	232	6.82
8	**MULTIMEDIA TOOLS AND APPLICATIONS**	22	72	3.27
9	**ACM TRANSACTIONS ON APPLIED PERCEPTION**	11	143	13
10	**GRAPHICAL MODELS**	10	239	23.9

*AC:Average number of citations per publication

Analysis Of Research Networks

According to Web of Science database search results and VOS viewer、Cite space for data analysis statistics, the search results in this area of literature related to the relevant countries/regions are 57, involving 915 institutions and 2759 authors worldwide. This chapter uses the search results of the data to analyze the literature from the following three directions: authors, institutions, and countries/regions. In addition, this chapter also analyses the most prolific authors, the institutions with the highest number of publications, and the countries/regions with the highest number of publications in terms of collaboration.

Citation Analysis

This section uses Histcite to analyze the citation of publications and gives the top 10 cited countries/regions, institutions, and authors, respectively. As shown in Table 4, firstly, from the direction of the Author, the most influential Author is Komura, Taku from the University of Hong Kong, whose NC is ranked first at 1308, followed by Van de Panne, Michiel from the University of British Columbia, who was cited 1103 times and is also the Author of the most frequently cited document. Third is Popovic, Jovan of the University of Belgrade, cited 1047 times.

In terms of Institutions, the top three N.C. rankings are the University of Washington (1682), Carnegie Mellon Univ (1592), and the University of British Columbia (1482), and the top 10 Institutions are economically developed countries. In terms of countries/regions, six Institutions are from the U.S., and the rest of the countries are from Canada, Scotland, South Korea, and Switzerland.

Analyzing by country/region, the USA has the highest number of NCs at 11,860, while Canada (2,787) and Germany (2,407) are ranked second and third in NC. Other than that, it is evident that the top 10 NCs are

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developed countries/regions.

Table 4 Papers cited by top 10 Countries、Regions、Institutions、Authors.

Rank	Author	NC	Institution	NC	Country/Region	NC
1	Komura,Taku	1308	Univ Washington	1682	USA	11860
2	Van de Panne , Michiel	1103	Carnegie Mellon Univ	1592	Canada	2787
3	Popovic , Jovan	1047	Univ British Columbia	1482	Germany	2407
4	Popovic , Zoran	960	MIT	1376	Peoples r China	1970
5	Saito , Jun	826	Univ Edinburgh	1353	Switzerland	1698
6	Lee , Jehee	788	Univ Toronto	916	South Korea	1641
7	Holden , Daniel	762	Seoul Natl Univ	913	Scotland	1381
8	Peng , Xue Bin	750	Stanford Univ	671	England	1234
9	Levine , Sergey	694	Univ Calif Berkeley	665	France	1073
10	Baran , Ilya	612	Swiss Fed Inst Technol	656	Ireland	688

Keyword Co-Occurrence Analysis

In this chapter of the thesis, the VOS viewer is used to analyze the co-occurrence of keywords, and the parameter Keyword Minimum Occurrences is set to 5 , then 156 thresholds out of 2928 keywords. Referring to Figure 11, each node in the figure is a keyword; the line between the nodes indicates that two keywords appear in the same document, the larger the diameter of the node, the higher the frequency of the keyword, and the lighter the color of the line represents the later the publication time of the document.

Figure 11 divides the 2928 keywords into 156 items, with 3029 connecting total lines strength, and also separates the 10 clusters with different colors; it can be seen that the keywords with the most frequent appearances are ranked in order as follows: "character animation," "animation," "motion capture," "motion" and "model." It is worth noting that "character animation" has the most significant node diameter, and"character animation" appears most frequently. "animation" appears less frequently than "character animation." However, "animation" is the earliest occurrence; the interval time between "animation" is slightly earlier than that of "character animation."

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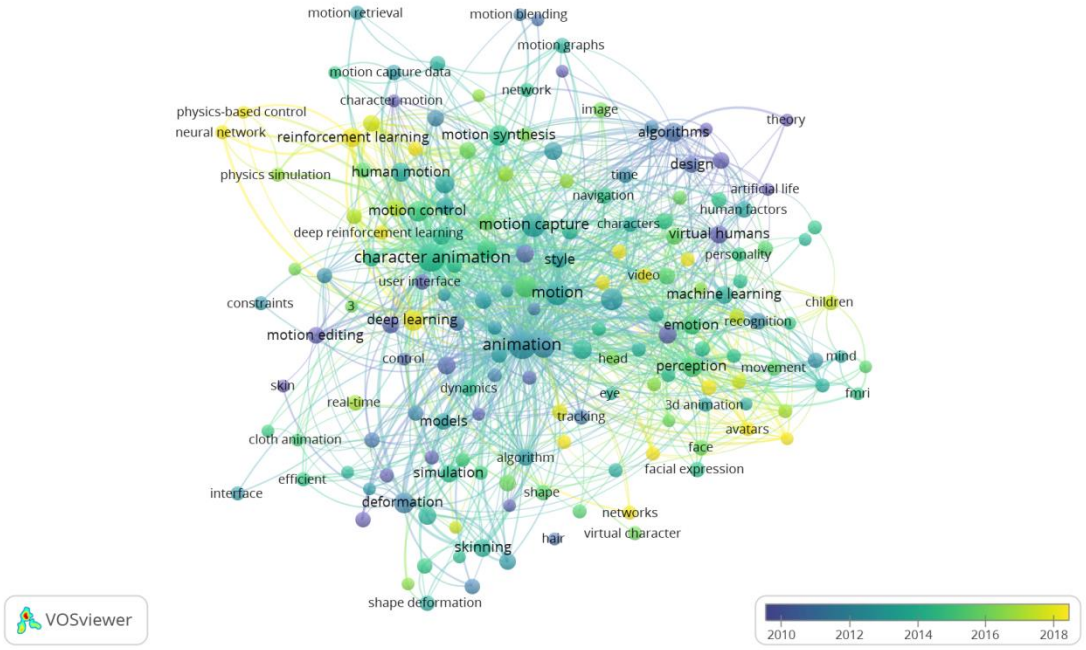

Fig. 11.The co-occurrence overlay of keywords

Author Collaboration Network Analysis

Using VOS viewer software to set the maximum number of authors per paper to 25, the minimum number of authors per paper to 1, and the minimum number of citations per author to 0, we get the result that 2759 authors are eligible. Table 5 lists the top 5 authors regarding the number of publications. Firstly, among these authors, the most prolific one is Komura, Taku, who has 26 publications, and this author belongs to the University of Hong Kong. Lee, Jehee has the highest number of co-authors of 13, and the number of co-authors of Komura, Taku and Van De Panne, Michiel and Noh, Junyong has the highest number of co-authors of 13, and the number of co-authors of Komura, Taku and Van De Panne has the lowest number of co-authors. Komura, Taku and Van De Panne, Michiel and Noh, and Junyong have the second highest number of co-authors, with 11. It is worth noting that Komura, Taku has the highest number of citations than Van De Panne, Michiel, and Noh, Junyong has the lowest number of citations, which is mainly because 4 of Noh, Junyong's publications have 0 citations and 1 has 0 citations. This is mainly because four papers published by Noh and Junyong have 0 citations, and 1 paper has 1 citation. Secondly, in terms of the number of collaborations, Liu, C. Karen, ranked fifth, has the most collaborations with Van De Panne, Michiel, with one paper indicating that these two authors have established relative collaborations. In contrast, the other four authors do not have collaborations with each other.

Table 5 The top 5 most productive authors

Rank	authors	Institution	NP	Co-number	NC	Begin	End	Main cooperators
1	Komura , Taku	Univ Hong Kong	26	11	1308	2011	2023	Shum, Hubert Ho, Edmond
2	Lee,Jehee	Seoul National University (SNU)	23	13	788	2007	2021	Hodgins , Jessica Hoyet ,

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								Ludovic
3	Van De Panne , Michiel	University of British Columbia	21	11	1103	2001	2023	Liu , C. Karen Yin , Kangkang Pettre,Julien
4	Noh,Junyong	Korea Advanced Institute of Science & Technology	19	11	174	2010	2023	Choi , Byungkuk Lee, Sung-hee , Jin, Xiaogang
5	Liu , C. Karen	Stanford Univ	18	4	390	2005	2023	Van De Panne , Michiel Pettre,Julien Ye , yuting Cani , marie-paule

*Co-number：Number of Collaborators；NC: the number of citations

Figure 5 shows the most linked collaborative network among authors from 2010-2020, which consists of 111 authors and 271 links. A node in the figure represents an author, the links between nodes represent papers with collaborations between authors, and the colors of the nodes and links represent the time regions of the published papers; the network is also divided into 12 main clusters, and the analysis in the direction of the timeline shows that authors Lee, jehee and Komura, Taku have the closest relationship with other collaborators and all of them have close cooperation with Hoyet, Indovic in 2014-2018. Meanwhile, Hoyet and Indovic have close cooperation with Multon and Frank, which shows that Hoyet and Indovic have close cooperation with Lee, jehee, Komura, Taku, and Multon; Frank authors have also established close cooperation between them. Multon, Frank, Komura, and Taku collaborated most closely from 2012 to 2014, which suggests that the two authors have a deep and longstanding relationship, while Liu Karen also had many collaborators from 2014 to 2018.

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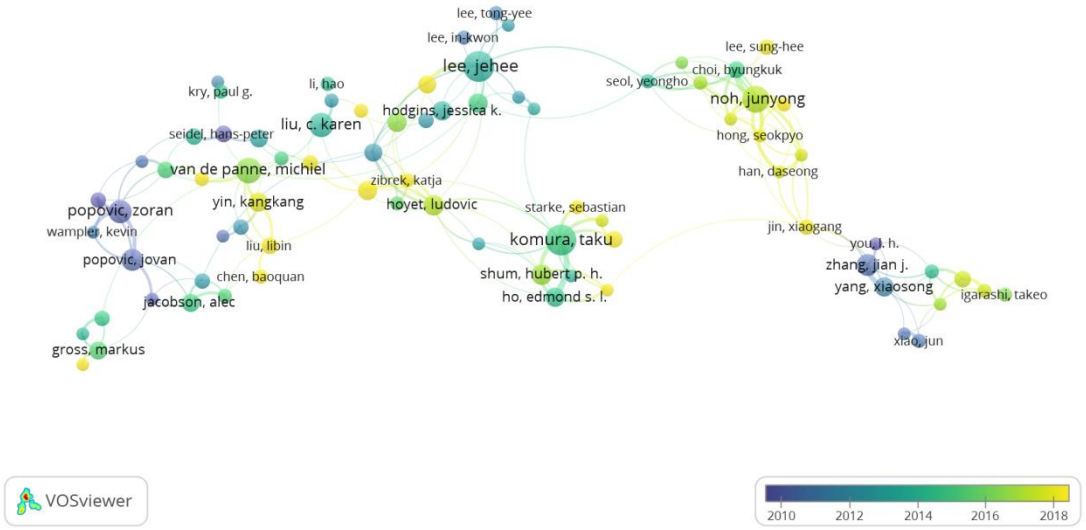

Fig. 5. The collaboration network of authors with timeline

The Most Productive Institutions

According to the Web of Science database search results and Vosviewer's processing of the data, a total of 915 institutions worldwide were involved; the reason why the number of institutions is more than the number of publications is that there are 2 or more institutions in one paper, Table 6 shows the top 5 most productive institutions, the most abundant is Zhejiang Univ (43 publications) The second most productive is Univ of California System (42 publications) in second place, followed closely by Swiss Fed Inst Technol (38 publications) in third place. Although Zhejiang Univ has the highest number of publications, it is close to the number of publications of Zhejiang Univ due to the citation frequency of 438. Univ of California System, which has only one less publication than Zhejiang Univ, has a citation frequency of 1921, which indicates that the article is highly regarded. Univ of California System has the highest citation frequency among the top 5.

Table 6 Top 5 most productive institutions

The top 5 most productive Institution				The top 5 most strongest Collaboration relationship		
Rank	Institution	NP	NC	Institution	LN	Main-co
1	Zhejiang Univ	43	438	Univ British Columbia	17	Swiss Fed Inst Technol , Stanford Univ , Univ Toronto , Disney Res , Texas A & M Univ ,
2	Univ of California System	42	1921	Carnegie Mellon Univ	14	Seoul Natl Univ , Swiss Fed Inst Technol , Univ Tokyo , Disney Res ,

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						Trunity Coll Dublin ,
3	Swiss Federal Institutes of Technology Domain	38	656	Swiss Fed Inst Technol	12	Univ British Columbia , Carnegie Mellon Univ , Univ Penn , Disney Res , Peking Univ , Univ Wisconsin ,
4	Centre National De La Recherche Scientifique Cnrs	33	370	Trinity Coll Dublim	11	Carnegie Mellon Univ , Disney Res , Rutgers State Univ , Inria , Univ Wisconsin , Sejong Univ ,
5	Korea Advanced Institute of Science Technology Kaist	32	391	Seoul Natl Univ	11	Korea Adv Inst Sci & Technc, Carnegie Mellon Univ , Univ Tokyo , Trinity Coll Dublin , Hangyang Univ ,
*NC: the number of citations				*LN:link number ; Main-co: Main cooperators		

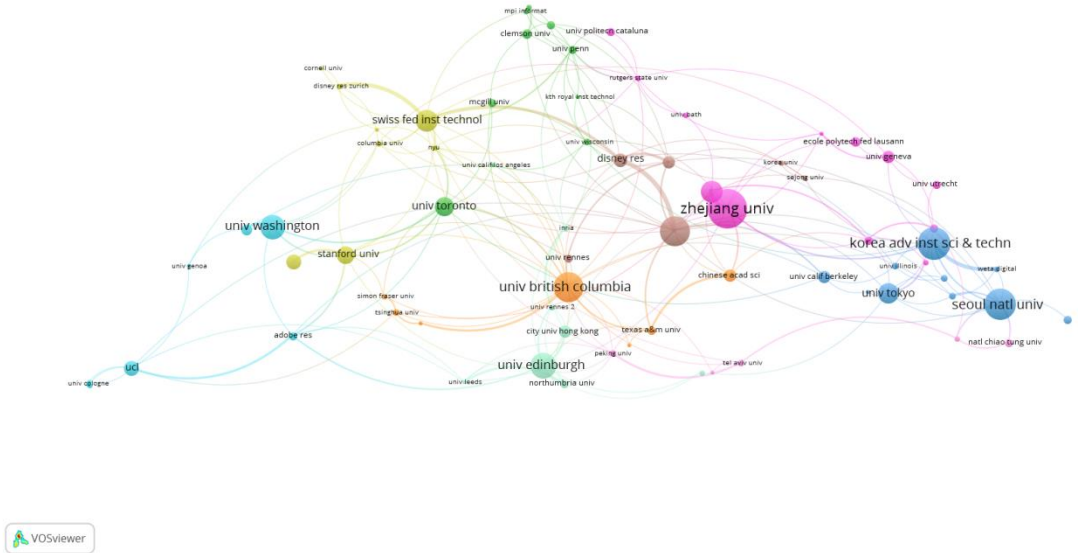

Fig. 6. Collaborative network with 69 Institutions

As shown in Figure 6, in exploring the collaborative analysis of the institution research network, the

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minimum number of papers published by the Institution is set to be 5, which produces a total of 184 nodes, which indicates that 69 Institutions have reached the set threshold. This summary selects the first 5 Institution clusters for analysis; the more significant the node in the Institution cluster, the larger the number of papers published by the Institution; if the nodes of the network exist in the area of the Institution, the larger the location of the network nodes, then it means that the Institution has a higher intermediary of the centrality of the Institution, this Institutions network is in the different Institution clusters of the bridge path, the nodes are connected represents that the Institution has a cooperation relationship between Institutions. The color of the line represents the time when the Institution first cooperated.

As shown in Figure 8 and Table 6, among the collaborative links between Institutions, the University of British Columbia has the most vital link strength and, at the same time, has the highest number of co-authored papers, which were mainly conducted and co-authored in 2005. Its primary local collaborators are Swiss Fed Inst Technol & Technc—Stanford Univ, Univ Toronto, Disney Res, Texas A & M Univ, etc. The only one in British Columbia is Carnegie Mellon Univ, and the main collaborators are Seoul Natl Univ, Swiss Fed Inst Technol, Univ Tokyo, Disney Res, Trinity Coll Dublin, and so on. It can be concluded that Swiss Fed Inst Technol and Disney Res have cooperated with the first- and second-ranked institutions, proving that they have established a good cooperative relationship. It is worth noting that Zhejiang University's centrality of 0.12 is the highest centrality among the cooperating institutions. From the geographical point of view, most of them have cooperated with global Institutions. Their central local collaborating institutions are Korea Adv Inst Sci & Technc, Bournemouth Univ, etc. Bournemouth Univ, etc. This shows that each country has to cooperate in animation character exploration. This direction is precious for research.

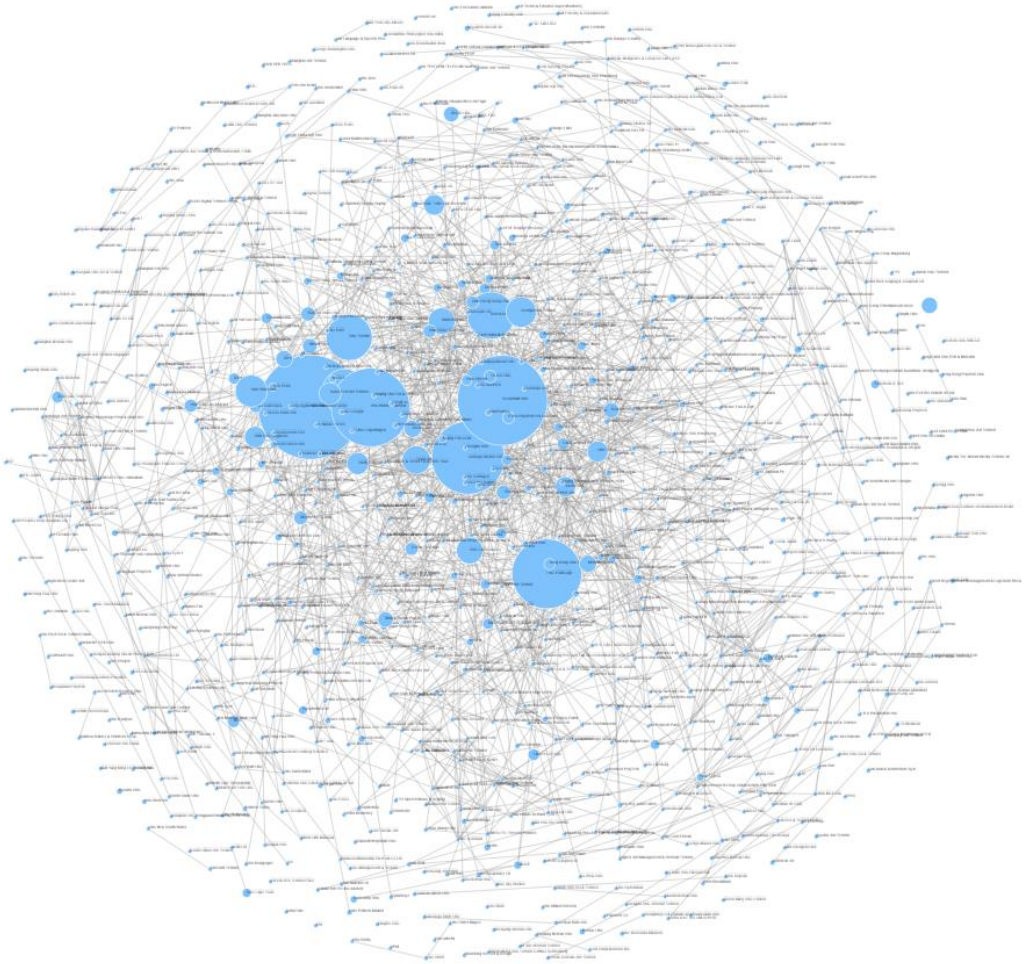

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Fig. 7. Collaborative network with 915 Institutions

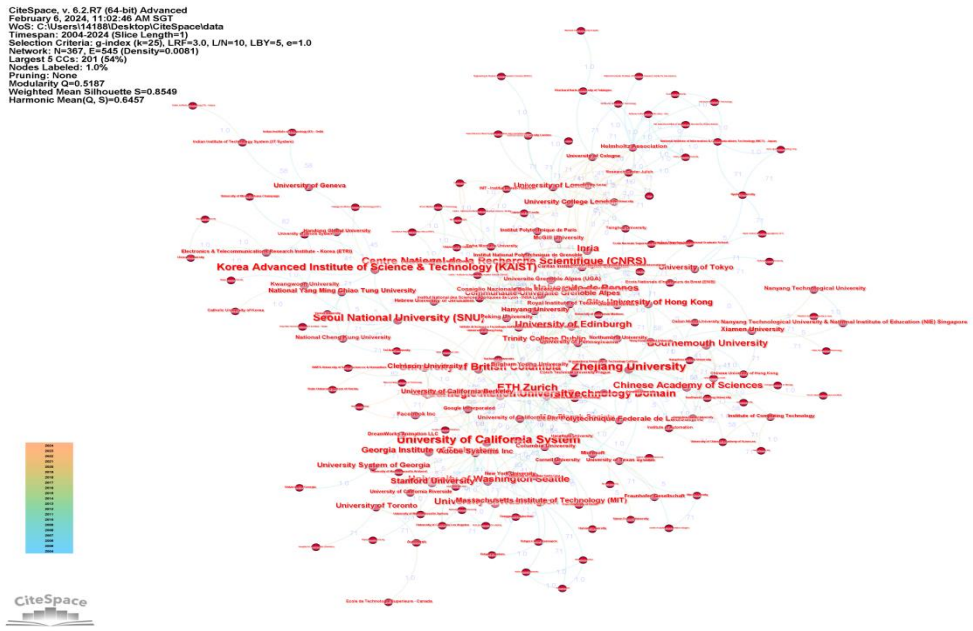

Fig. 8. The top5 collaboration network of Institutions

The Most Productive Countries/Regions

The important indicator of whether the field is valued or not is determined by the number of papers published by each country/region; table 7 lists the number of documents published by the top 10 countries/regions in the search results; from the table, it can be concluded that the USA is the country with the highest number of papers published in the field with 278 papers, the second place is China with 212 papers. The third place is South Korea, with 120 papers; in the top 10, only Peoples R China and Taiwan are developing Countries/Region, and the others are developed Countries/Region, in addition to. However, the number of papers published by USA is ranked first, and the citation of the paper is also the highest, as high as 11860, which shows that the paper's attention is high. The attention of the paper is high.

Table 7 The Number of Documents Published by The Top 10 Countries/Regions in The Search Results

Rank	Countries/Regions	NP	NC	%/1043
1	USA	278	11860	26.6
2	Peoples R China	212	1970	20.3
3	South Korea	120	120	11.5
4	England	93	1234	8.9
5	Canada	79	2787	7.5
6	France	77	1073	7.3
7	Switzerland	61	1698	5.8
8	Germany	60	2407	5.7
9	Japan	60	645	5.7
10	Taiwan	36	309	3.4

To better study the collaborative output of Countries/Regions to get the Countries/Regions Collaboration Network, CiteSpace was used to analyze the Countries/Regions computationally. A total of 29 nodes and 130 links (with a network visualization) are generated in the network. Each node represents

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Countries/Regions, and the links between the nodes represent a paper co-authorship between Countries/Regions. The larger the diameter of the node indicates that the paper output of these Countries/Regions is higher, and the larger the diameter of the node shows that the paper output of these Countries/Regions is higher. The larger the diameter of the node indicates that the Countries/Regions have more paper outputs, and the more lines between the nodes indicate that the Countries/Regions cooperate more closely with each other. As shown in Figure 9, it can be seen that the first node centrality is the United States, followed by China, the third is South Africa, the fourth is Canada, the fifth is France, the sixth is England, and the seventh is Japan, which means that the United States is a highly influential Countries/Regions in animation character research, and the other Countries/Regions are very different from it.

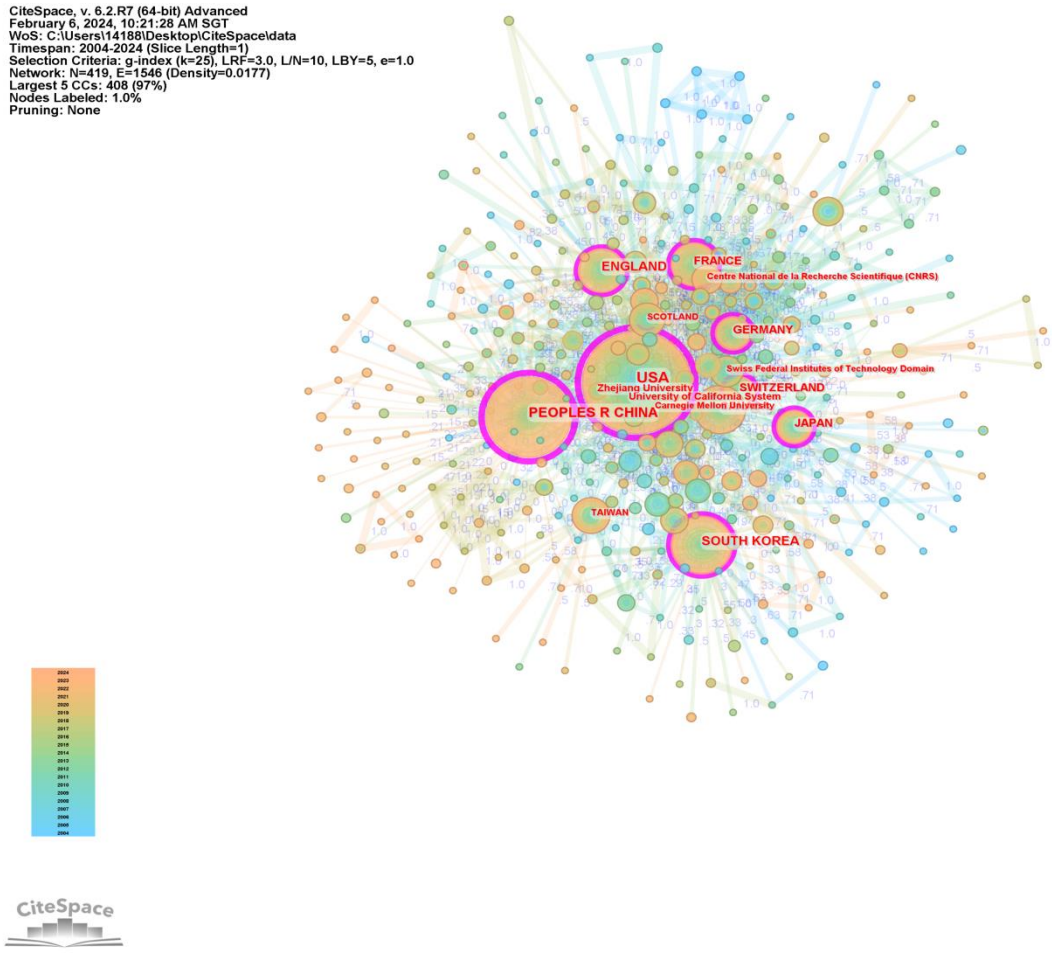

Fig. 9. The collaboration network of countries/regions

Figure 10 shows the information on cooperation between Counties/Regions. The figure shows that the United States has the most extensive network of scientific cooperation relationships with other Countries/Regions in terms of the number of papers, and the United States has the most extensive partners in terms of scientific cooperation partners, such as China, Germany, New Zealand, and Canada. Although China is the first in terms of the number of papers published, it is the second in terms of the number of documents co-operated with other Countries/Regions, which indicates that the cooperation between China and other Countries/Regions is not very close except for UK, USA, and Canada. Apart from that, there is more cooperation between developed countries, such as the USA, UK, France, and New Zealand, which shows that they have established strong cooperation relationships and frequent academic exchanges. In contrast, South Africa has the least amount of cooperation with other countries, suggesting that South Africa is mainly independent in its research on animated characters.

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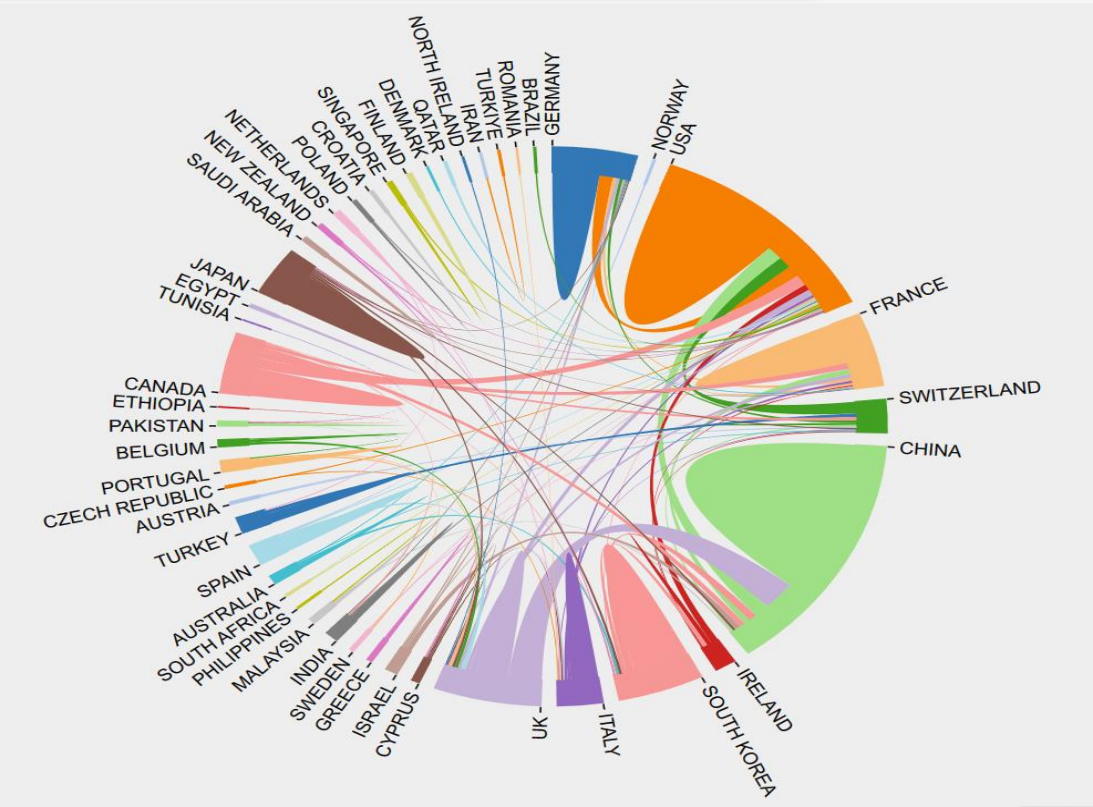

Fig. 10. The overview of collaboration between countries/regions.

Burst Detection Analysis

The emergent word detection function is a prominent feature of Citespace, which allows us to get a macro-to-micro view of academic research in a particular field, predict which directions will continue to be explosive in the future, and evolve from a single to a diversified trend. To further explore the research frontiers in the field of animated characters, this section detects and analyses bursts of cited authors, references, journals, and Counties/Regions and Institutions.

First, Table 8 detects the bursts of authors who cited the literature from 2004-2024 and lists the information related to the top 10. ZORDAN VB (2006) had the earliest outbreak, but it did not last. HOLDEN D had the most substantial outbreak of 24.79, ranked the first, and lasted for an extended period, which indicates that his research is a recent hotspot since 2018-2024 has had a significant impact on the field, suggesting that his research is a contemporary hotspot.

Table 8 Top 10 Cited Authors with the Strongest Citation Bursts

Rank	Cited Authors	Year	Strength	Begin	End	2004 - 2024
1	HOLDEN D	2017	24.79	2018	2024	
2	PENG XB	2016	21.92	2018	2024	
3	STARKE S	2020	16.97	2020	2024	
4	ZHANG H	2020	16.97	2020	2024	
5	BERGAMIN K	2020	14.28	2020	2024	

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6	KINGMA DP	2020	14.28	2020	2024	
7	ZORDAN VB	2006	13.44	2006	2010	
8	LIU LB	2012	12.96	2016	2022	
9	WON J	2018	12.79	2018	2024	
10	LEVINE S	2014	12.61	2016	2021	

Secondly, burst detection was carried out, and results were obtained for the cited references from 2004-2024, which are shown in Table 9, from which scientific research shows that the top three are Holden D (2017), Kovar L (2002) and Holden D (2016) respectively.

The outbreak intensity is 19.69, 18.62, and 16.19, respectively, which indicates that these are the frequently cited references in this research area. In addition, the others did not last till 2024, while Bergamin K (2019) had a citation burst persistence till recently, which indicates that this literature is a recent research hotspot.

Table 9 Top 10 References with the Strongest Citation Bursts

Rank	References	Year	Strength	Begin	End	2004 - 2024
1	Holden D, 2017, ACM T GRAPHIC, V36, P0, DOI 10.1145/3072959.3073663, DOI	2017	19.69	2018	2022	
2	Kovar L, 2002, ACM T GRAPHIC, V21, P473, DOI 10.1145/566570.566605, DOI	2002	18.62	2004	2007	
3	Holden D, 2016, ACM T GRAPHIC, V35, P0, DOI 10.1145/2897824.2925975, DOI	2016	16.19	2017	2021	
4	Treuille A, 2007, ACM T GRAPHIC, V26, P0, DOI 10.1145/1239451.1239458, DOI	2007	13.06	2008	2012	
5	Peng XB, 2017, ACM T GRAPHIC, V36, P0, DOI 10.1145/3072959.3073602, DOI	2017	13.03	2018	2022	
6	Bergamin K, 2019, ACM T GRAPHIC, V38, P0, DOI 10.1145/3355089.3356536, DOI	2019	12.16	2020	2024	

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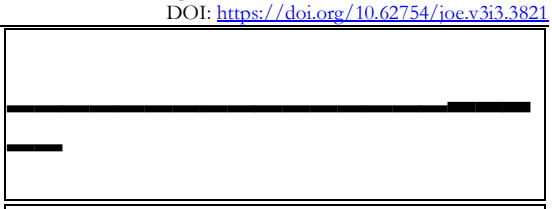
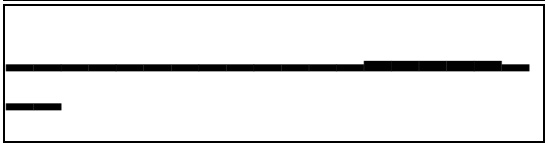
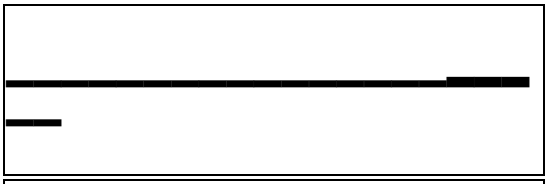
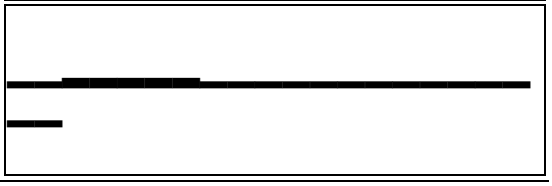
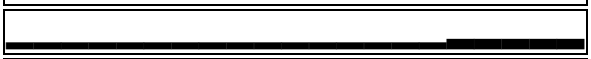
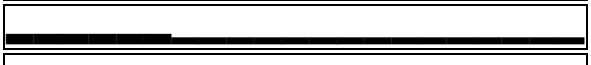
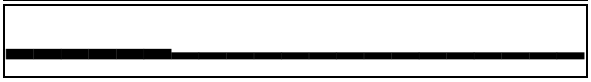
7	Park S, 2019, ACM T GRAPHIC, V38, P0, DOI 10.1145/3355089.3356501, DOI	2019	12.09	2020	2022	
8	Liu LB, 2016, ACM T GRAPHIC, V35, P0, DOI 10.1145/2893476, DOI	2016	11.8	2017	2021	
9	Zhang H, 2018, ACM T GRAPHIC, V37, P0, DOI 10.1145/3197517.3201366, DOI	2018	11.59	2020	2022	
10	Liu CK, 2005, ACM T GRAPHIC, V24, P1071, DOI 10.1145/1073204.1073314, DOI	2005	11.27	2006	2010	

Further, Table 10 detects the burstiness of the journals in which the cited documents were published from 2000-2022 and lists the top 10 journals in which the most robust outbreaks were published in the mentioned documents; ARXIV has the highest outbreak intensity of 26.05, ranked second and third are IEEE I CONF COMP VIS (23.96) and PROC CVPR IEEE (18.24)), the first rated time of outbreak persistence is P 2002 ACM SIGGRAPH (2006-2012), and the tied second-ranked time of outbreaks are IEEE I CONF COMP VIS (2019-2024), PROC CVPR IEEE (2019-2024), COMP GRAPH (2004-2009) and COMPUTER GRAPHICS (2004-2009), which indicates that COMP GRAPH and COMPUTER GRAPHICS erupted earlier. The eruption period of IEEE I CONF COMP VIS and PROC CVPR IEEE is the most recent, which proves to be a hotspot for the near future.

Table 10 Top 10 Cited Journals with the Strongest Citation Bursts

Rank	Cited Journals	Year	Strength	Begin	End	2005 - 2024
1	ARXIV	2019	26.05	2021	2024	
2	IEEE I CONF COMP VIS	2009	23.96	2019	2024	
3	PROC CVPR IEEE	2005	18.24	2019	2024	
4	ADV NEUR IN	2005	17.36	2020	2024	
5	THESIS	2016	15.15	2016	2020	
6	MULTIMED TOOLS APPL	2015	14.01	2021	2024	
7	COMP GRAPH	2004	13.29	2004	2009	
8	P 2002 ACM SIGGRAPH	2006	12.52	2006	2012	
9	COMPUTER GRAPHICS	2004	12.51	2004	2009	

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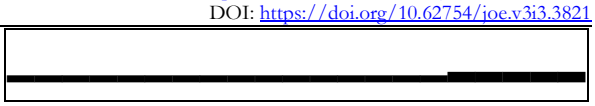
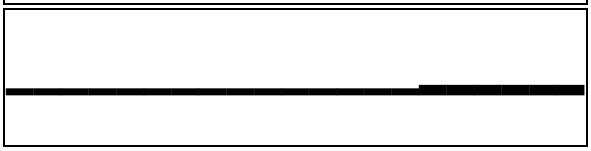
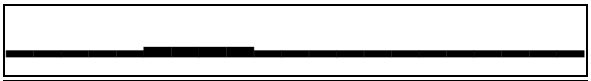
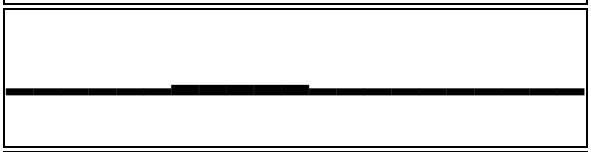
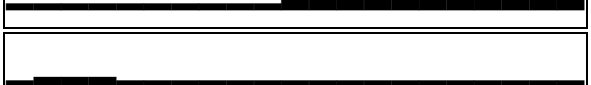
10	PR MACH LEARN RES	2018	11.82	2020	2024	

In addition, Table 11 also detects bursts for institutions that published papers in the field from 2004-2024 and lists the names of the top 10 institutions with the most robust outbreaks. Centre National de la Recherche Scientifique (CNRS) is ranked first; it has an outbreak intensity of 5.55, closely followed by the University of Washington (5.35) and University of Washington Seattle (5.35). The most considerable citation outburst length is from Universite de Rennes (2014-2024), and the shortest is from Zhejiang University (2005-2007) and earlier.

Table 11 Top 10 Institutions with the Strongest Citation Bursts

Rank	Institutions	Year	Strength	Begin	End	2004 - 2024
1	Centre National de la Recherche Scientifique (CNRS)	2009	5.55	2019	2024	
2	University of Washington	2007	5.35	2009	2012	
3	University of Washington Seattle	2007	5.35	2009	2012	
4	Inria	2008	4.6	2019	2024	
5	University System of Georgia	2007	4.25	2007	2012	
6	Swiss Federal Institutes of Technology Domain	2005	3.95	2010	2014	
7	University of Geneva	2005	3.64	2005	2008	
8	Massachusetts Institute of Technology (MIT)	2004	3.57	2004	2009	
9	Universite de Rennes	2014	3.54	2014	2024	
10	Zhejiang University	2005	3.39	2005	2007	

Finally, Table 12 detects bursts for the output countries of papers published in this field from 2004-2024 and lists the top 10 Counties/Regions with the most vigorous bursts. It can be seen that PEOPLE R CHINA is ranked first with an intensity of 25.36, followed by JAPAN (4.09), SWITZERLAND (3.75), and SINGAPORE (3.17).SINGAPORE has the most extended citation burst duration, which is 7 years. SINGAPORE (3.17). The most extended time duration of citation explosion in SINGAPORE is 7 years. The citation explosion of JAPAN (2004-2005) was the first to appear, but it stopped after that; the citation explosion of PEOPLES R CHINA has lasted up to now, indicating that the results of its thesis are the hot direction of the recent research. This suggests that the results of its papers are the desirable direction of current research.

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Table 12 Top 4 Countries with the Strongest Citation Bursts

Rank	Countries	Year	Strength	Begin	End	2004 - 2024
1	PEOPLES R CHINA	2005	25.36	2021	2024	
2	JAPAN	2004	4.09	2004	2005	
3	SWITZERLAND	2004	3.75	2010	2013	
4	SINGAPORE	2006	3.17	2011	2017	

Keyword Analysis

Keyword analysis is an essential tool for literature mining, as well as statistics and analyses of important words with a high number of occurrences in the publication literature, and the basic principle of keyword analysis is to determine the hotspots and their later trends through the changes in the number of frequency of word occurrences. In this chapter, the keywords are analyzed using two tools, VOS viewer and Citespace, and the keyword burst detection analysis, Citespace timeline visualization, and co-occurrence frequency analysis functions are used to find research frontiers, hotspots, and future development trends.

Burst Detection Analysis of Keywords

This chapter uses Citespace to analyze the keyword burst exploration of papers published in this field from 2004 to 2024. Table 13 shows the top 10 keywords ("deep learning," "reinforcement learning," "motion," "neural networks," "human animation," "virtual characters," "motion planning," "capture," "virtual humans," and "inverse kinematics") with the highest number of citations. "Human Animation, Virtual Characters, Virtual Humans" triggered the earliest and highest persistence of 8 years, indicating that "Human Animation, Virtual Characters, Virtual Humans" was the research hotspot in the period of 2004-2012; secondly, "Deep Learning, Reinforcement Learning" triggered seven years in the same period (2017-2024), and they both lasted until recently, with the difference that "deep learning" is more intense than "reinforcement learning." reinforcement learning," it has the highest intensity of 11.97 , "Deep learning" is a popular research field in recent years and current frontier research field; finally, the shortest burst period is "motion" appeared in 2007-2008.

Table 13 Top 10 Keywords with the Strongest Citation Bursts

Rank	keywords	Year	Strength	Begin	End	2004 - 2024
1	deep learning	2017	11.97	2018	2024	
2	reinforcement learning	2015	9.62	2018	2024	
3	motion	200	6.03	200	200	

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		6		8	9	
4	neural networks	2006	5.84	2018	2022	
5	human animation	2005	5.44	2013	2012	
6	virtual characters	2005	5.13	2005	2012	
7	motion planning	2006	5.02	2010	2012	
8	capture	2007	4.92	2007	2013	
9	virtual humans	2005	4.41	2005	2012	
10	inverse kinematics	2005	4.35	2017	2019	

Citespace assigns a more appropriate label to each cluster by extracting keywords and displaying the cluster's name on the right. The results and evolution of the history of the field are visualized by performing a timeline analysis of keywords from 2004-2024, setting the conditions in Citespace as follows: time slicing time of 1, selecting keywords to process the generated timeline, and selecting the first 15 keyword clusters. As shown in Figure 12, in the timeline graph, keywords are spread out in the clusters they belong to according to the year of their appearance, while the time of the first appearance of the keyword determines its order in the timeline. Firstly the keywords are clustered from Cluster #0-#13 and #30 in the following order: #0: physics-based animation, #1: character animation, #2: motion culture, #3: facial animation, #4: cloth simulation, #5:computer animation, #6:virtual reality, #7:deep learning, #8:scratch, #9:human factors, #10:carbon monoxide, #11:animated character, #12:2d character animation, #13:animal models, and #30:automatic dance choreography creation, with clusters #1:character animation lasting the longest until it reaches 20243, and #10:carbon monoxide lasts the shortest.

In addition, clusters #0, #1, #2 first appeared in 2000, or even earlier, while #0 clusters in the 2000-2010 time began to gradually increase the results, indicating that this cluster at that time by many scholars, into a popular research area, but in 2010-2017 the cluster research results began to become fewer, indicating that the study of scholars started to decrease; cluster #3 first appeared in 2005, in 2005-2013 more research results to become a popular area, after the time gradually cooled; except that cluster #4 appeared in the same time as #5and #6, but cluster #4 ended earlier than them, except for a brief concentration of research results in 2004, and gradually cooled down after 2004, but until it became active in 2010-2016, and then except for that research results at other points of time around 2022, the cluster began to become less

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popular in the future. Around 2022 there are few research results at different time points; clustering #5 lasts from 2004 to 2023, except for the central clustering in 2004, and secondly active in 2007-2008, there are fewer research results at other times, and there are more research results at different time points in 2010-2015; Cluster #8:scratch had very little research until 2004-2013 due to technical limitations, but after 2013 it started to increase and became a popular area of study and has continued to do so until recently.

During the development of the clusters, clusters #0, #1, #2, #4, and #5 all appear as diamond-shaped graphs with large areas, which indicates that they all seem to mediate keywords with high centrality, namely, cluster #0 "physics-based animation," cluster #1 "character animation," cluster #4 "cloth simulation," cluster #5 "computer animation " all of these keywords influence the trend of these clusters. As the subject area of animation continues to evolve, the themes and keywords of the clusters have changed over time; Table 14 shows a summary of the top 15 clusters of information, each showing keywords with LLR values.

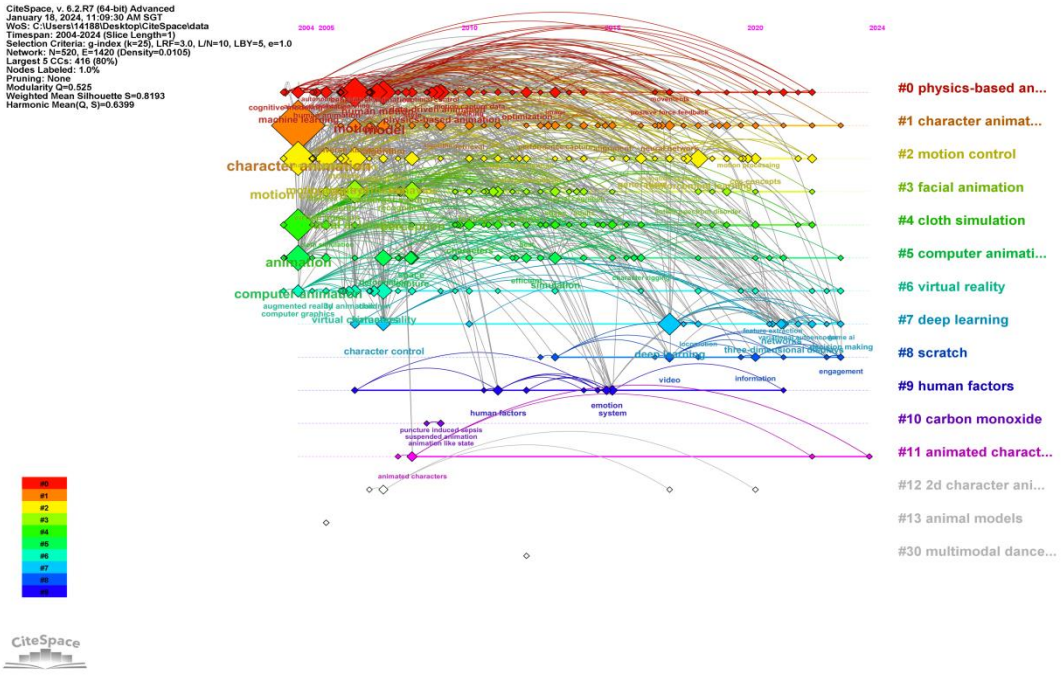

Fig. 12. The timeline review of keywords

As in Figure 13, Citespace was applied to select the range of All in one: Clustering optimizing layout and style to generate 9 thematic clusters, #0motion capture data in red, #1motion field in orange, #2inverted pendulum model, #3dynamic triangle mesh and #4hand- drawn character in green, #5virtual other in sky blue, #6camera movement in ultramarine, #7dance composition in purple, and #4hand- drawn character in pink. 8anatomy modelling: Drawn character and #5virtual other in sky blue, #6camera movement in ultramarine, #7dance composition in purple, #8anatomy modelling in pink. Drawing the character is associated with #1Motion Field and #6Camera Motion, #3Dynamic Triangle Mesh and #5Virtual Other and #7Dance Composition, which suggests that Dynamic Triangle Mesh is more closely related to #5Virtual Other and #7Dance Composition.

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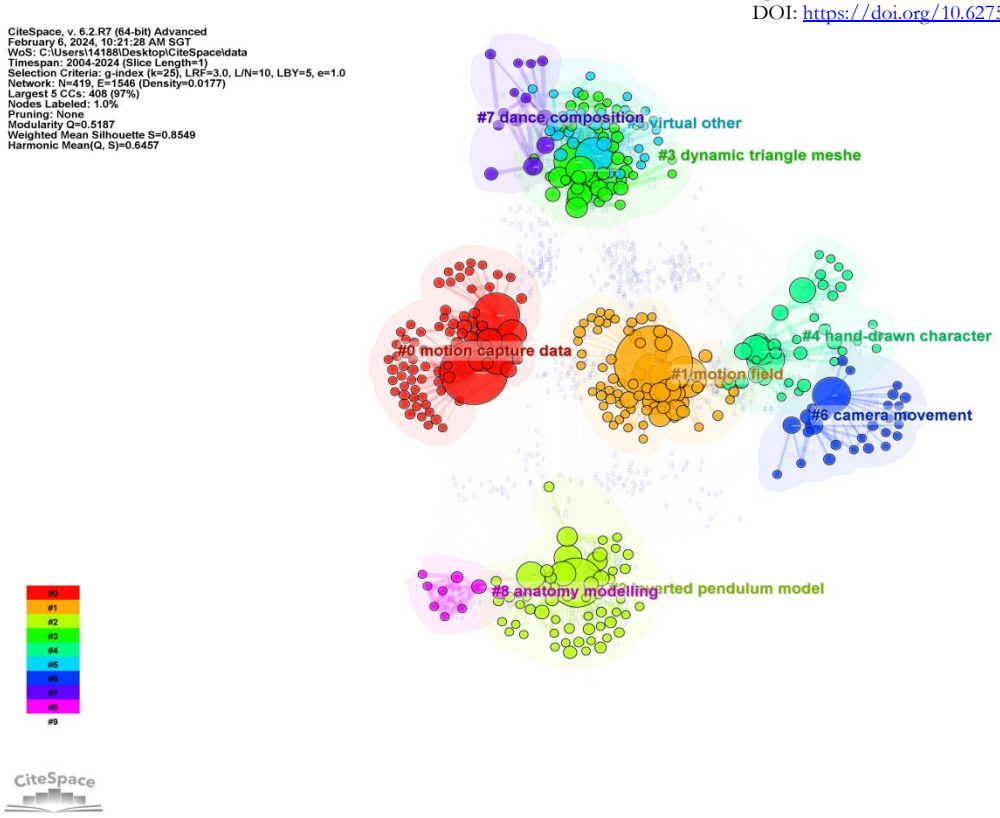

Fig.13.The topic of the collaboration network of countries/regions

Table 14 A summary of the top 15 clusters of information

Cluster ID	Mean (Year)	keywords ranked by LLR
#0: physics-based animation	2007	**physics-based animation; character animation; motion capture; optimal control; character simulation | computer animation; machine learning; cognitive modeling; behavioral modeling; synthetic characters** animation; motion; control; character; physics-based simulation; human; data; balance; biped
#1: character animation	2004	character animation; user-specified skeleton; reinforcement learning; multiagent reinforcement learning; crowd simulation | inverse kinematics; artificial intelligence; evolutionary computation; collision avoidance; full-body motion animation; character; scanning; skeleton; user-specified motion; human; retrieval; content-based; unrest
#2: motion capture	2004	motion capture; motion graphs; human motion; motion capability; capability metrics | motion control; facial animation; spatial-temporal constraints; statistical dynamic models; human body animation motion; capture; synthesis; network; data

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		animation; character; learning; reinforcement; simulation
#3: facial animation	2006	facial animation; active appearance model; animation retargeting; intuitive animation control; virtual characters | perception; biological motion; anticipatory performance; cues; head animation; active; appearance; control; retargeting social; nonverbal; spectrum; disorder; dyadic
#4: cloth simulation	2005	motion editing; character animation; spatial relationship; motion retargeting; collision detection | cloth simulation; adaptive remeshing; collision detection; sketching interface; multimodal behavior realization animation; character; linear; deformation; skinning motion; retrieval; harmonic; function; spherical
#5: computer animation	2004	computer animation; face perception; perceptual narrowing; gabor kernels; threat avoidance | character animation; dynamic skin deformation; time-dependent 3d trigonometric curve; visual attention; subspace dynamics virtual; camera; games; viewpoint; planning algorithm; generation; keyframe; algebra; drilling
#6: virtual reality	2007	virtual reality; user interface; computer animation; adaptive character animation; animation blending | virtual characters; 3d graphics; data visualization; mobile device; 3d animation distance; earth; semantics; comparison; analysis medical; muscles; diagnostic; dermatomyositis; human-in-the-loop
#7: deep learning	2017	deep learning; neural networks; human motion; character interactions; motion style generation | character animation; solid modeling; virtual environments; self-representing avatar animation; plausibility illusion control; reinforcement; electronics; algorithm; based transfer; pornography; fusion; generalization; training
#8: scratch	2021	human-computer interaction; cave-like immersive environments; role-playing game; third-person perspective; virtual reality cave | building information modeling; non-player characters; virtual drill; physical collision; fire evacuation evacuation; modeling; drill; building; fire empathy; cave; third-person; autism; perspective
#9: human factors	2011	**human factors; social inferences; virtual humans; cognitive dimensions; effort shape analysis | unsupervised learning; bayesian methods; motion capture; action segmentation; social inferences** facial; generation; animation; system; facs-based human; social; intentions; analysis; cognitive
#10: carbon monoxide	2009	**carbon monoxide; hydrogen sulfide; microcirculatory blood flow; mitochondrial**

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		respiration; nitric oxide; sepsis; suspended animation; tissue oxygenation carbon monoxide; hydrogen sulfide; microcirculatory blood flow; mitochondrial respiration; nitric oxide; sepsis; suspended animation; tissue oxygenation
#11: animated character	2008	**animated characters; virtual avatars; eye tracking; image system; light image enhancement | image system; light image enhancement; image design; virtual avatars; eye tracking** image; system; light; design; embedded gaze; tracking; avatars; pupil; perception
#12:2d character animation	2007	**as-rigid-as-possible (arap); local control; shape deformation; 2d character animation** as-rigid-as-possible (arap); local control; shape deformation; 2d character animation
#13: animal models	2005	**evolution; ontogeny; genomics; animal models; fetal programming** evolution; ontogeny; genomics; animal models; fetal pro
#30: automatic dance choreography creation	2012	**automatic dance choreography creation; multimodal dance modeling; music-driven dance performance synthesis and animation; music-to-dance mapping; musical measure clustering** automatic dance choreography creation; multimodal dance modeling; music-driven dance performance synthesis and animation; music-to-dance mapping; musical measure clustering

Discussion

The previous section of this paper analyses the retrieved literature. The results also show that the research on animation characters has been extended to other disciplines. By analyzing the keywords in the past two years, the hotspots of animation character research focus on "motion capture," "virtual characters," "computer animation," "data visualization," characters," "computer animation," "data visualization," "animated character" and "animated character." animated character," "facial animation" and "physics-based animation," etc. These keywords appear most frequently with the highest frequency. With the continuous development of the discipline, virtual reality, regular algorithms, dynamic capture, physical attributes, animated characters, etc., have several directions in this chapter to discuss the current research hot issues respectively.

Current Topical Issues

Animation characters receive attention, which is one of the essential elements affecting animation sales and ratings, and the animation industry can effectively drive the development of the economy and promote cultural exchanges. How to improve the performance of animation characters out of performance has become the focus of academic researchers. First, as of the latest update, some current hot issues in character animation research include Interactive and real-time animation. With the rise of virtual reality (VR), augmented reality (AR), and gaming technologies, interest in interactive and real-time character animation is growing. This includes creating characters that can dynamically respond to user input or adapt to changing environments in real-time (Shum et al., 2008; Yang, 2024); 2 Artificial Intelligence and Animation,

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Incorporating Artificial Intelligence (AI) techniques into character animation is an important topic. Researchers are exploring how AI can be used to automate certain aspects of animation production, enhance the realism of character behavior, and even generate animation autonomously(Reddy et al., 2024) ; 3 Motion Capture and Performance Animation: Motion capture technology continues to advance, enabling animators to capture more nuanced and realistic performances(Hu et al., 2024; Llobera & Charbonnier, 2023). Researchers are exploring techniques to integrate motion capture data into character animation pipelines and to improve the fidelity of captured performances(Hu et al., 2024) ; 4 Inclusion and Diversity: There is a growing realization of the importance of inclusivity and diversity in character design and performance(Dumont & Bonenfant, 2023; Rane et al., 2023). Researchers are investigating how to create characters that accurately reflect different cultural backgrounds, genders, and identities, as well as how to avoid perpetuating stereotypes or prejudices in character animation(Rutherford, 2023).Lawson also emphasizes the significance of communication, shared experience, and comprehension in developing design knowledge. However, the knowledge accessible for conceptual and professional growth in character animation design is restricted, and exchanging experiences in this sector is extremely limited. As a result, more than thorough information on character design is required (Lioi, 2009); 5 Ethical considerations, as AI and other technologies evolve in the field of animation, there is a need to address ethical concerns such as the potential impact on employment in the animation industry(Safdar et al., 2020), the fidelity of characters' expressions and emotions, and the potential of AI-driven animation algorithms with possible biases(Hancock et al., 2020); 6 Health and well-being animation: there is growing interest in the potential of animation to promote health and well-being, particularly in areas such as mental health, education, and therapy. Researchers are investigating how character animation can be used to convey therapeutic messages, facilitate learning, and support emotional expression and communication(del Valle-Canencia et al., 2022; Liang & Hwang, 2023); 7 Environmental Sustainability: Like many other industries, the animation industry is under pressure to be environmentally sustainable. Researchers are exploring ways to reduce the carbon footprint of the animation production process, such as optimizing rendering algorithms, minimizing resource consumption, and adopting environmentally friendly production methods. The field will continue to evolve as technology advances and societal priorities shift(Fan & Feng, 2021; Lange & Santarius, 2020).

Secondly, character design has received attention as one of the most critical elements affecting animation sales and ratings. In contrast, the animation industry can effectively drive economic development and promote cultural exchange. How to improve the performance of animation characters out of performance has become the focus of academic researchers. Animation characters can be considered multidimensional objects in academic research, involving the cross-study of several disciplinary fields such as psychology, cultural studies, child development, sociology, etc. REPRESENTATION AND CHARACTERISATION: Researchers may focus on the ways in which animated characters are represented, including how factors such as gender, ethnicity, and cultural background are presented in characterization and the effects of this presentation on the audience. Psychology and Characterisation: Researchers may explore the psychological characteristics of animated characters, such as personality traits, psychological development, etc., and how these characteristics affect the character's behavior and decision-making in the story. Narrative and Story Structure: Scholars may examine the storylines of characters in animated works, including the challenges, conflicts, and solutions that characters face and how these elements build the narrative structure of the animated work. Social and cultural contexts: Researchers may focus on the social and cultural contexts in which animated characters are embedded and how these contexts influence the characters' behaviors, values, and ways of interacting. Audience reactions and influences: Scholars may examine audience reactions and attitudes towards animated characters, including the effects of emotional connection, identification, and behavioral imitation. Education and child development: Some studies may focus on the role of animated characters in child development and education, including aspects such as how characters shape children's values, attitudes, and behavioral patterns. Marketing and commercial influences: Researchers may focus on the influence and marketing strategies of animated characters in the commercial marketplace and how character images are used to promote and sell products, with the popularity of a character influenced by cultural and symbolic representations. The essential characteristics and success of animation and animated films depend on the culture in which the character design is formed (Yu & Sao, 2022).

Finally, Andrew O. Enaifoghe and Nthabiseng E. Makhutla mention that in "Exploring Cultural Diplomacy

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as Soft Power through Cultural Communication Exports: A Model of Power for Promoting Peace and Security" the dynamics of the trend of economic globalization, it is both the integration of nations and peoples and the critical point for nations and peoples to maintain their own culture (Enaifoghe & Makhutla, 2020). The following are some of the critical points in the process of cultural integration. Maintaining the characteristics and development of the culture of each country is contradictory to the modern context. Taking the creation of visual animation symbols as a foothold, focusing on respecting the traditional culture of the original under the extraction, adapted in the intelligent, technological contemporary combined with the world's fashionable aesthetic elements, so that the visual animation symbols of the theoretical and practical research (Schneider & Wright, 2021), through the understanding of the tradition and the development of the contemporary concepts related to the sources of combing analysis of the tradition to contemporary art, analyzing both creative form and creative thinking (Earley & Ang, 2003). Exploring the diversity of contemporary global culture, respecting the diversity of various national cultures, and the innovation and breakthrough of visual animation symbols under intelligence are the research difficulties (Earley & Ang, 2003; Furferi et al., 2024), summarising what the corresponding characteristics and necessary conditions of visual animation characters, and what are the insights into their visual creation and design methods? They urgently need to be explored and researched.

Future Trends and Challenges

Although the study of animation characters has been developed for many years, there are some new challenges and bottlenecks with the progress of scientific and technological development; in the new digital era, the speed of innovation and creation is faster than in any previous period, primarily known as the fourth industrial revolution some cutting-edge technological industries, such as artificial intelligence, big data analytics and blockchain, and other new technologies triggered a series of animation characters related to the cultural preservation and symbolic heritage and animated characters are problematic. There is also an impact on the existing culture and symbols in animated characters(PUMAGUALLE et al., 2023). With the development of AI technology, machine creation will be the mainstream in the future, so is it necessary to change the current way of creation and use AI generation and other methods to replace manualized creation? Intelligence and ethics will also create conflicts, a problem that needs to be solved in the future(Hassani et al., 2020). Therefore, there is a need for scientific researchers to refine this body of knowledge to continue to promote innovation and creativity and to ensure that the animation character system continues to evolve to accommodate the new industry(Nguyen & Ruberg, 2020; Shen et al., 2015).

In countries around the globe that are rich in historical and cultural heritage and genetic resources, traditional knowledge and cultural systems are valuable assets that contribute to actions such as indigenous, rural, and local economic development, cultural heritage preservation, and sustainable development (Zerbe, 2022). Such as traditional culture and global integration into art and symbols; therefore, using modern animation character knowledge systems to develop new rules to protect the protection of conventional culture and non-heritage culture is also an auspicious direction(Woodhead, 2023).

The protection of animation characters is to protect cultural wisdom and design the fruits of labor. Therefore, traditional culture is a crucial incentive for innovation and creativity in character animation(Fan & Feng, 2021); in the current context of sustainable development proposed by the countries in the academic world is the lack of animation character design framework(Harder, 2023), animation characters and culture and symbols to seek a solution to the contradiction between these three points is also a future direction of research(Zhang & Romainoor, 2023; 두월교 & 박재연, 2021).

The economic and technological development of countries worldwide needs to be balanced, and the level of animation in different regions is different (Fan & Feng, 2021). Economically, animation can drive the growth of a country's GDP to a certain extent, and at the same time(Liu et al., 2023; Liu, 2021; Montoya et al., 2023), it can also spread the culture of its people to other peoples and countries(Ćwikła et al., 2020), so how to find a balance among technological innovation, cultural preservation, and economic development is a great challenge for governments. Technically, animated characters have a strong influence. An excellent animated character image represents culture, symbols, and technology, which can play a decisive role in the economic market revenue. It can also promote cultural exchange through dissemination. However, transforming cultural and symbolic achievements into new products and services for the benefit of society

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and molding animation characters successfully under the situation of information asymmetry are the current development problems.

Limitations

In character animation research, this paper provides researchers with a comprehensive review of the development of animation character research over the past 20 years through bibliometric analyses from 2004-2024. However, this paper has some limitations; firstly, the databases selected for this paper are relatively unique, and the search formulae set up may lead to the omission of specific literature. Later studies will consider a variety of databases and limit the search to a more relaxed scope to collect data. Although there are limitations, this paper presents the development of animation character research over the past 20 years from various perspectives to help researchers in the field become more familiar with its evolution.

Conclusion

This paper analyses the literature related to animation in a multidirectional way, revealing the basic information, knowledge framework, research hotspots, and future development challenges of the field. Firstly, through the primary risk of measuring the quantity of literature, the relevant literature characteristics are presented, including annual publication-related data, literature types, and highly cited literature. Secondly, research collaboration networks are analyzed in three directions: authors, institutions, and countries/regions. After that, the literature authors, references, and sources were detected and analyzed for bursts, respectively, followed by keyword analysis and keyword burst detection to explore the possible hotspots and future trends in the field. Finally, future trends and challenges are discussed and summarised below:

1)Firstly, the number of annual publications in the literature shows a stepwise increase. However, in some years, there is a slight fluctuation in the upward trend of growth, but the citation frequency of the literature is proliferating. In terms of the type of literature, Thesis accounted for 76.75%, Conference Proceedings Papers accounted for 20.32%, Review Papers 1.34%, and in terms of the field of publication, ACM TRANSACTIONS ON GRAPHICS and NEUROPSYCHOLOGY were the most frequently cited journals. NEUROPSYCHOLOGIA magazine journals are the most popular. Komura, Taku (1308) is the most highly cited literature, and the citation path shows that the study of animated characters is expanding to other disciplines. Apart from this, the most prolific journals are ACM TRANSACTIONS ON GRAPHICS, COMPUTER ANIMATION AND VIRTUAL WORLDS, and COMPUTER GRAPHICS FORUM.

2) Secondly, in terms of research network studies, in terms of authors, Komura, Taku, and Lee, Jehee are the most prolific authors, and Noh and Junjong have the widest range of partners. Regarding the number of articles published by institutions, Zhejiang Univ is the most productive, and Univ of California System and Swiss Fed Inst Technol have the most partners. In terms of countries/regions, the United States is (278) the most prolific country, and the United States has the highest intermediary centrality and the most partnerships with other countries/regions.

3) Then, in terms of burst detection, Holden D (24.79) had the most vigorous bursts, which were late and continued into the recent past. In terms of reference citations, Holden D (2017), Kovar L (2002) and Holden D (2016) are the frequently cited references in this research area, while for the journals in which the literature is published, ARXIV (26.05) is the highest, and in second and third place are IEEE I CONF COMP VIS (23.96) and PROC CVPR IEEE (18.24), while Centre National de la Recherche Scientifique (CNRS) and PEOPLES R CHINA are the most cited organizations and Countries/Regions with the highest citation explosiveness, respectively.

4) After that, in terms of keyword analysis, the hotspots of animated character research focus on "motion capture," "virtual characters," "computer animation," "data visualization," characters," "computer animation," "animated character," and "animated character." "data visualization," "animated character" and "animated character." animated character," "facial animation" and "physics-based animation," etc. The keywords "deep learning" and "reinforcement" are detected by keyword burst detection. The keywords "deep learning" and "reinforcement, "learning motion," "neural networks," and "human animation" are

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gradually being used. The keywords "deep learning" and "reinforcement," "learning motion," "neural networks," and "human animation" have gradually become the cutting-edge directions of research, and the eight clusters obtained through the timeline analysis reveal the research hotspots and main lines of research in this field.

5) Finally, based on the analyzed results, the current research hotspots and possible future research hotspots and challenges are discussed. This study shows that the discipline of animation characters will develop with the development of science and technology, and there are also some challenges and bottlenecks that will require more in-depth research by scholars in the future to adapt to the development of the economy and science and technology.

This paper provides a comprehensive analysis of publications related to animated characters from 2004-2024 to help scholars with characters animation research interests better understand the field's evolution. This paper also needs to include that the singularity of the database selection and the search criteria may have led to the omission of specific literature. At the same time, this paper focuses on providing a panoramic view of the field rather than a more in-depth analysis of the details that emerge. Therefore, this paper has some limitations.

Declarations

-Ethics approval and consent to participate

Not applicable.

Consent for Publication

All authors read and approved the final manuscript. We all agree that the submission can be used to publish the article.I confirm the corresponding author has read the journal policies and submit this manuscript in accordance with those policies.

Availability of Data and Materials

Data will be made available on request.The (DATA TYPE) data used to support the results of this study are included in the article.

Competing Interests

There are no potential competing interests in our paper, and all authors have read the manuscript and agreed to submit it to your journal. We confirm that the contents of the manuscript have not been published or submitted for publication elsewhere.

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Authors' contributions

AH collected the figures and data for the article; SSJ performed the checking of the icons and data; CY analysed and interpreted the figures and data for the article and was the main contributor to the writing of this manuscript. All authors read and approved the final manuscript.

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