



Tomas Bata University in Zlín
Faculty of Multimedia Communications

The Thesis of the Dissertation

Efficiency of Creation in Digital Audiovisuals
The Concept of Non-Linear CGI-AV Pipeline

Efektivita práce v digitální audiovizuální tvorbě
Koncept nelineární CGI-AV pipeline

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1. ABSTRACT

This transdisciplinary thesis proposes an innovative non-linear approach to producing high-quality digital audio-visual (AV) outputs while reducing the time and manpower typically required in the traditional one-way linear CGI-AV pipelines. With central focus on efficiency of creation that would foremost benefit small to mid-size CGI-AV artist teams, the thesis provides a comprehensive comparison between linear and non-linear pipelines, highlighting their respective advantages and limitations and recommending the use of procedural strategies. The research underpinning the thesis aims to identify the calculable aspects of quality of CGI-AV outputs from the content creation perspective. Furthermore, after evaluating and defining the existing methods that would lead to the measurement of efficiency in the context of CGI-AV production, the research initiates the creation of new experimental methods to advance the field, particularly pertaining to quantifying iteration. Anticipating practical implementation, the thesis proposes effective strategies for rapid prototyping through acceleration of iterative cycles by procedural and automated approaches in the CGI-AV development process. In addition, the thesis explores the artist's changing role within new technological landscapes. It suggests novel modes of interaction between the artistic and the technical, creating the concept of art-nodes where the routine tasks are handed over to technology in order to support deeper human art-flow and promote artistic creativity and experimentation. In its scope, this work aspires to offer valuable insights and practical solutions for improving the overall efficiency and quality of audio-visual production, ultimately benefiting both the artist and the CGI-AV industry as a whole. The thesis results in the delivery of a complete, theoretically substantiated and practically tested concept of Non-Linear CGI-AV Pipeline, immediately applicable with a combination of existing software, and open the future development of an all-in-one software solution.

2. INDEX

1.	Abstract.....	4
2.	Index.....	5
3.	Introduction	7
3.1	The CGI-AV Context of the Dissertation	7
4.	Thesis Goals and Research Questions.....	9
4.1	Primary Goals.....	9
4.2	Secondary Goals.....	9
4.3	Research Questions	10
5.	Methodology.....	11
5.1	Qualitative Methods	11
5.1.1	Content Analysis Method 1: Review of Industry Literature	11
5.1.2	Content Analysis Method 2: Semi-structured Interviews.....	11
5.1.3	Thematic Analysis	11
5.2	Quantitative Methods	11
6.	Current state of the industry and key terms.....	13
6.1	Linear Pipeline	13
6.1.1	CGI Injection Into Live Action Shooting	13
7.	Theoretical Part	16
7.1	Measuring Quality.....	16
7.2	Iteration	16
7.3	Efficiency	17
7.3.1	Efficiency Formula Introduction	17
7.3.2	The Terms and Parameters.....	18
7.3.3	From Effectivity to Efficiency: The Formula Development	19
7.3.4	Tool-formula for Efficiency.....	21
7.3.5	Efficiency Formula as a Viability Determinant.....	24
7.3.6	Conclusion	25
7.4	Art-Nodes	25
7.5	Applied Procedurality and Automation	28
7.6	Guidelines To Improve Efficiency.....	28

7.7	The Concept of Non-linear CGI-AV Pipeline.....	29
7.7.1	Blueprint of Non-Linear Pipeline with Existing Technology	30
7.8	Conclusion Of Theoretical Part	30
8.	Experimental Part – Quantifying Iterations	31
8.1	Image Difference Methods	31
8.2	Reading timeline checked frames.....	33
8.3	Machine Iteration.....	33
9.	Practical Part	34
10.	Results.....	35
10.1	Primary goal results	35
10.1.1	Research, Experiments and Theory.....	35
10.1.2	Conceptualization and Application of Non-linear CGI-AV Pipeline	35
10.2	Secondary goal results	37
10.2.1	The Artist: Efficient CGI-AV Production.....	37
10.2.2	Prototyping: Strategies for Efficiency.....	38
10.2.3	Economics: Non-Linear vs. Linear Pipeline	38
11.	Contribution of the Dissertation Work	40
11.1	Present Contribution	40
11.2	Further research platforms.....	40
11.3	Future Plans	41
12.	Conclusion of the Dissertation Work.....	42
13.	List of Used Literature and Sources	43
14.	List of Used Figures and Tables	47
14.1	Figures	47
14.2	Tables.....	47
15.	List of Used Audiovisual Works	48
16.	Professional Biography.....	49

3. INTRODUCTION

In the context of the rapidly changing CGI-AV field, this explorative transdisciplinary thesis aims to create theoretical and practical framework for utilizing cross-industry insights into production efficiency, validated through case studies. Its ultimate goal is to assist freelancers and small teams in remaining economically viable while artistically creative in the highly competitive market of CGI-AV products.

3.1 The CGI-AV Context of the Dissertation

Being themselves part of a small CGI-AV team battling for success in the contemporary competitive environment, the author's basis for the inception of this research project is his reflection on the nearly two decades of personal experience in the CGI-AV field, and anticipation of the future challenges.

CGI-AV is a domain which constantly keeps moving forward while grappling with the problem of determining the most suitable tools and software for creation. The issue of suitability has two dimensions. The first dimension is the perspective of the artist as a digital creator, while the second dimension is economic - driven by the need to monetize one's art to make a living. Both dimensions are interconnected by the question of efficiency, with the premise that if artists had to handle fewer technical aspects, they could remain longer in the '*art-flow*' (Chemi, 2016, p. 37-50), experienced by an artist at the moment of the upmost height of creative moment. Hence, the time saved on the technical aspects of production should make CGI-AV makers more economically competitive. This is owed to the proportional shift, whereby streamlining of technical necessities results in freeing more artistic space-time. This concept underlies the goals for this research and encompasses the questions of automation, artistic role, quality evaluation and CGI-AV industry production processes and economies.

The ground for the broad scope of engagement, in this thesis, with the technologies which suitably underpin CGI-AV artistic creation, was first prepared by explorations into specialist technical aspects. Thus, the work the thesis presents was first engendered, and is still informed, by the author's initial case studies of automatic tools for rigging which accelerated the creation of puppets by 480 times, automatic tools for editing assistance, and data preparation tools for editing from filming. Another significant concern informing the thesis is the position of the professional artist within the CGI-AV industry from the geo-economical point of view. There are several interrelated areas of current debate on the pressing problems in CGI-AV production. They include the exodus of senior CGI-AV experts abroad, the economic competitiveness of Central European studios in the CGI-AV field, and the decentralization of production which takes into account the impact of unprecedented events, such as, most recently, COVID-19, or the rise of AI.

The research outputs of this work are deliberately foremost focused on freelancers and smaller teams. If the smaller market players increase the efficiency of their CGI-AV production processes, the working dynamic between large foreign studios and regional creative cells can become more balanced, resulting in improved economic conditions for the latter. Furthermore, enhancing efficiency could lead to an increase in the quality of CGI-AV works, as it allows for faster production while maintaining the same level of quality. Hence, a major part of this thesis engages with the question of how to best define efficiency, and then seeks to find and recommend the most efficient practical solutions efficient for creating CGI-AV works in the context of the current and future marketplace.

The multitude and variety of the above discussed issues necessitates a transdisciplinary experimental approach, as it bridges the geo-economic issues concerning small creative units of Central Europe, the highly technical and technological context of their artistic I/O¹ and the scientific objectives of the dissertation thesis. The following chapter on the research goals, accompanied by the research questions that underpin them, maps out the scope of this dissertation thesis research.

¹ The term ,data I/O‘ means data input and output..

4. THESIS GOALS AND RESEARCH QUESTIONS

4.1 PRIMARY GOALS

The dissertation aims to fulfil three primary goals which cover the theoretical foundations and outputs of this research.

Primary Goal 1: to determine a core definition of efficiency in CGI-AV.

Primary Goal 2: to create practical guidelines for the most efficient production pipeline software solution.

Primary Goal 3: to establish the role of the artist within the relationship between technological options and artistic I/O.

4.2 SECONDARY GOALS

The next step aims to turn the theoretical outputs of the primary goals into viable practical possibility.

Secondary Goal 1: Define efficient production of CGI-AV works from the perspective of individuals/freelancers.

Secondary Goal 2: Define efficient production of CGI-AV works from the perspective of compact creative teams.

Secondary Goal 3: Define efficient production of CGI-AV prototypes.

4.3 RESEARCH QUESTIONS

- (1) How can efficiency in the creation of CGI-AV works be defined?
- (2) To what extent is efficiency just automation?
- (3) How can the same amount of CGI-AV works be produced in less time, with fewer experts, while maintaining quality?
- (4) Which aspects are integral to the measurement of quality of creation from the perspective of CGI-AV production?
- (5) How does the iterative process contribute to efficiency?
- (6) Can iterations be quantified?
- (7) How to implement the efficiency theory in a practical framework?
- (8) What general guidelines are applicable for the most efficient approach to CGI-AV creation?
- (9) How is the artist's role changing within new technological landscapes?
- (10) How can the technical possibilities and artistic I/O be most efficiently connected?
- (11) How does procedurality contribute to efficient interaction between the technical and the artistic?

5. METHODOLOGY

This transdisciplinary thesis, grounded in exploratory research, utilizes a mixed-method approach which serves as an empirical means to define efficiency and bridge the gap between the subjectivity of quality and the calculable aspects of quality in CGI-AV outputs.

5.1 QUALITATIVE METHODS

5.1.1 Content Analysis Method 1: Review of Industry Literature

The main literature sources were chosen for their empirical-evidence supported content concerning the current state of the CGI-AV industry and for their insights into the most inspirational and innovative approaches, with *Creativity, INC² . Overcoming the Unseen Forces That Stand in the Way of True Inspiration* (2014) by Ed Catmull providing the main source of inspiration for identifying the relationship between quality, iteration and efficiency.

5.1.2 Content Analysis Method 2: Semi-structured Interviews

The semi-structured interviews, serving as the preliminary research, were conducted to gain first-hand perspective into the operational issues of CGI-AV creation from its experienced practitioners from global CGI-AV companies, foregrounding the main topics for analysis - such as current solutions in the responders' workflows from the aspect of their production pipelines.

5.1.3 Thematic Analysis

The qualitative research outputs identified the following concepts:

Workflow, Automation, Pipelines, Procedurality, Project manager, Efficiency, Pipeline manager, Game engines, Iterative process, Pilots, Prototypes, Artistic I/O

5.2 QUANTITATIVE METHODS

This research methodology involves systematic empirical investigation of observable phenomena via statistical, mathematical, or computational techniques. However, this dissertation is highly experimental and contains elements of

² CATMULL, Ed. *Creativity, Inc.: an inspiring look at how creativity can - and should - be harnessed for business success by the founder of Pixar*. 18th edition. USA: Bantam, 2014. ISBN 9780593070109.

research uncertainty. Thus, some of its methods had to be developed specifically to accommodate the experimental research objectives, as demonstrated in detail in the experimental section.

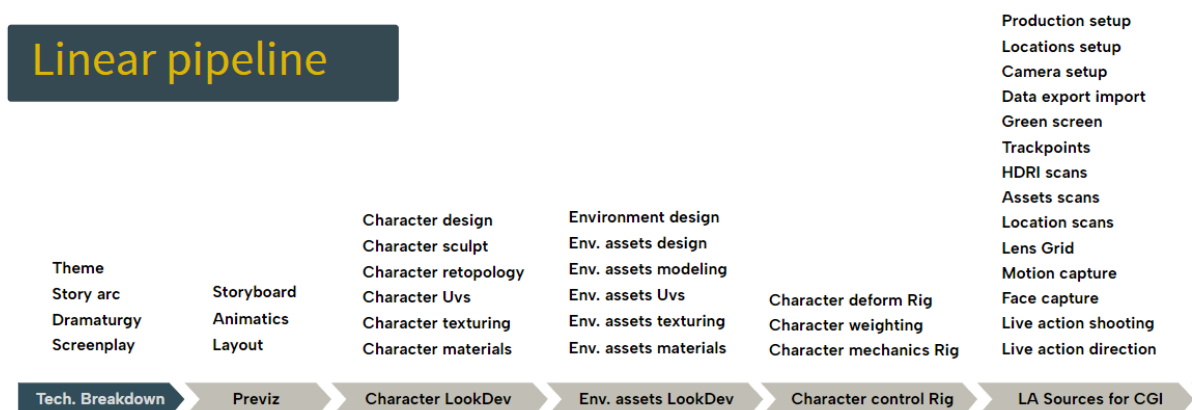
6. CURRENT STATE OF THE INDUSTRY AND KEY TERMS

6.1 LINEAR PIPELINE

The current state of the CGI-AV industry still is, and has been for decades, anchored in linear mindset and linear pipeline organization. In the pre-digital era, the term ‘linear pipeline’ meant the subsequently progressing stages of creation, based on the linear chemical processes inherent in the use of raw film material. Since then, in the last 50 years, technology has moved towards almost absolute digitalization, with the hardware power multiplying every year. Concurrently, however, the linear creation approach has stayed almost unchanged, still rooted in the chemical processing of the film stock. Thus, majority of productions follow a process of CGI-AV creation which remains within the constraints of a linear pipeline, proceeding gradually, part by part, through a long sequence of consecutive artistic checks where the creator decides about the quality of the given phase before moving onto the next. Hence, paradoxically, contemporary CGI-AV workflows still conform to historical workflows born under completely different technological conditions.

6.1.1 CGI Injection Into Live Action Shooting

Although pipelines may vary depending on the project or studio, the linear pipeline is used both in the CGI creation and live-action footage creation, and in the situations where the CGI is injected into live-action footage. The following example showcases a complex linear pipeline where every workflow and process of the CGI approach is included.



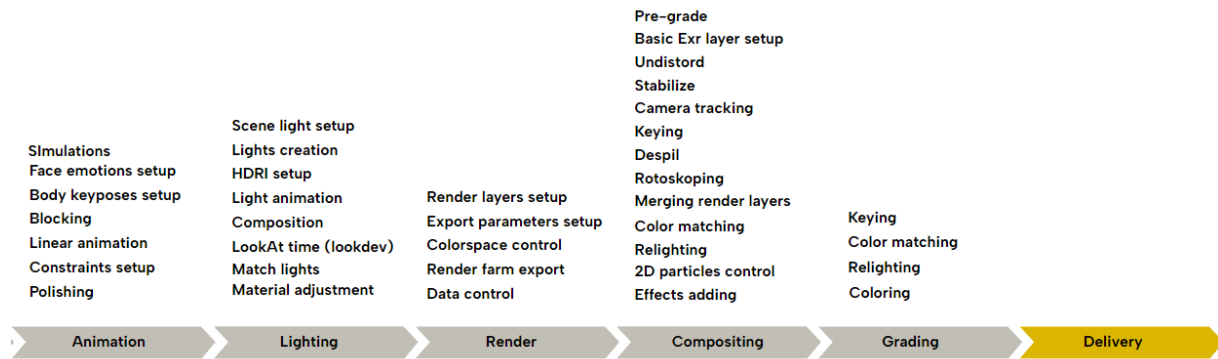


Fig. 6.1 Linear pipeline of the injection of CGI elements into live action footage

The above-described illustration demonstrates the rigid step-by-step progress of a CGI-AV project along a linear pipeline. Although this process is time-tested and **effective**, its **efficiency** is to be questioned. Here, the technical (thus automatable) work outweighs the space of creative artistic input by more than 60% (see the ratio of the technical/black to the artistic/yellow in the Fig. 6.8).

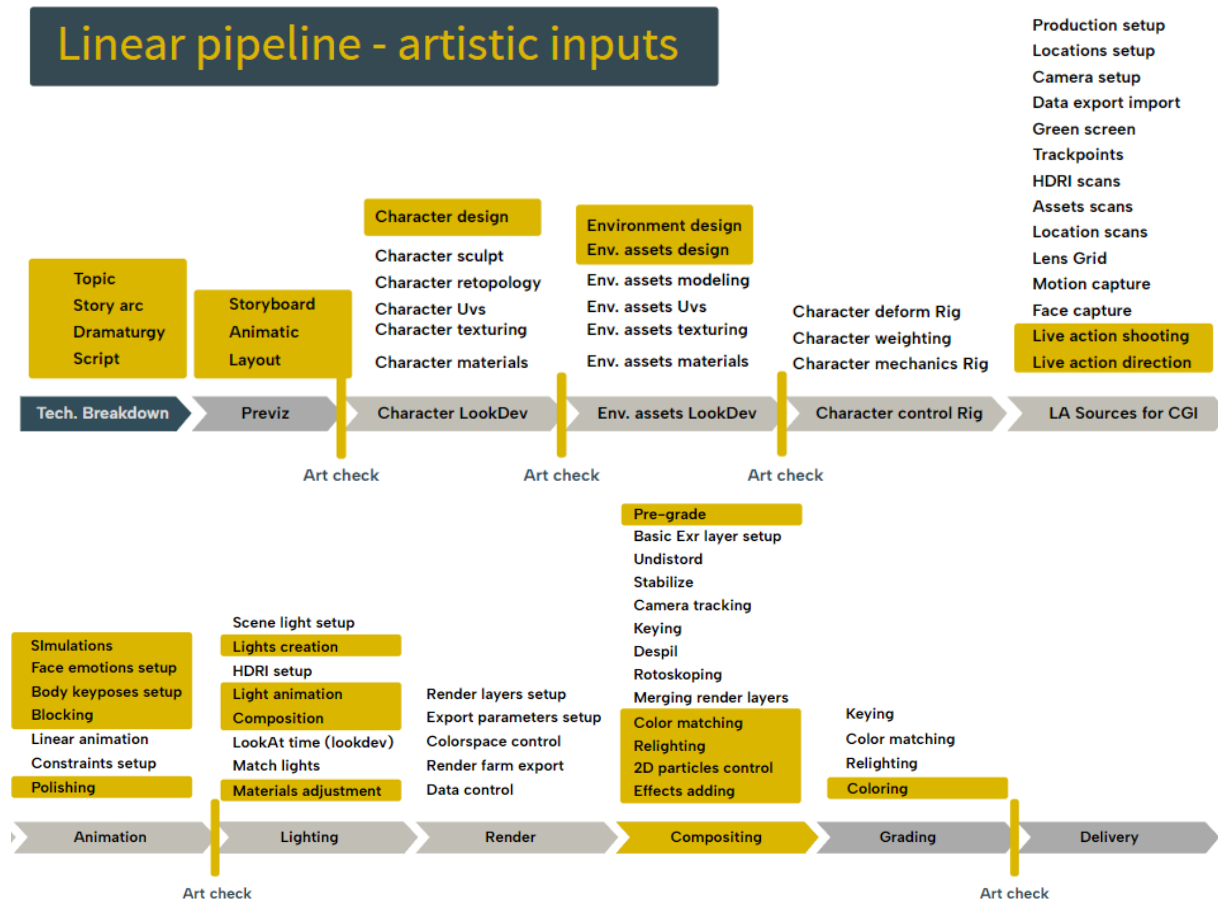


Fig. 6.2 Linear pipeline's artistic control checks.

Linearity is deeply ingrained in the working habits of CGI practitioners. However, its rigid approach inherited from pre-digital era makes it challenging to make efficient retrospective revisions, whereby modification often requires significant recreation. Furthermore, linear pipeline stifles the artistic with the technical, when the technical could potentially be streamlined and reconfigured to better serve the art-flow. However, on the market there are options that offer partial solutions for more efficiency driven technology utilization within the CGI-AV industry, and these will be considered in the forthcoming chapters:

- Linear Pipeline Managers
- Project Managers
- Procedurality and Procedural Systems
- Gaming Industry
- Node systems
- Procedural Pipeline Managers
- Automation

7. THEORETICAL PART

This exploratory work faces a degree of research uncertainty; for some parts, there are no existing procedures or methods. Hence, the theoretical section of this dissertation functions as part of the experiment itself, introducing new concepts and definitions of terminology in the field of CGI-AV creation, which are nevertheless firmly grounded in the current state of the art.

7.1 MEASURING QUALITY

Although conceptualizing and assessing quality is from many angles a subjective undertaking, this thesis asserts that when looked at from the CGI-AV production perspective, quality can be determined through its relationship to the measurable aspects of the creation process. Thus, following a complex intellectual examination, one of the key focus points of this dissertation research is on the metric determination of quality. The inspiration for addressing this problem has come from Ed Catmull's contemplation of Pixar's approach to creation, where *'[q]uality meant that every aspect—not just the rendering and the storytelling but also the positioning and the marketing—needed to be done well, which meant being open to reasoned opinions, even when they contradicted our own.'* (Catmull, 2014, p. 299) Here, the breakthrough idea for the measurement was inspired by Catmull's suggestion that *'[i]n general, the movie steadily improves with each iteration,'* (Catmull, 2014, p. 111) Thus, Catmull's assertion introduces a possibility of a calculable aspect of quality. If it is iteration which increases improvement, then Catmull's information provides a vital base for identifying the measurable element of quality.

7.2 ITERATION

Libor Nemeškal, the head of the Editing Department at Tomas Bata University in Zlin, Audiovisul Arts, recently shared an analogy about the old practices of film editors before transparent tape became widely available. In the days when specialized editing tape had not yet been invented, filmmakers had to edit their films by cutting and stapling sections together, bonding the film material with adhesive and waiting for it to set overnight. Thus, to complete one iteration of reviewing the whole editing phase would take around twelve hours. However, when the tape was introduced, they could simply cut the film material as needed, secure it with tape and view their results instantly. This allowed for subsequent fast iterations, which led to a much more efficient way of working. Thus, this story demonstrates how innovation can greatly enhance efficiency. Furthermore, it also foregrounds the relationship between efficiency and iteration, whereby a previously time-consuming process can be turned into a series of iterations.

An iteration can be seen as a systematic revision of the current phase of a creative project across that entire project. Thus, iteration refers to an overall review of the entire project, whereby the review results in an adjustment, hence a change, of that project. However, when seeking a software solution to identify iteration, without a contextually objective evaluation, determining what constitutes an iteration is highly subjective. Therefore, when looking for a software answer, it is crucial to establish measurement techniques that accurately identify and quantify iteration in CGI-AV projects. The experimental part of the dissertation addresses and resolves this question.

7.3 EFFICIENCY

From improving the practices of the analogue-era film editors to the utilization of contemporary linear pipeline managers which speed up and streamline the creation of CGI-AV, the biggest VFX studios endeavour to be as effective as possible. The industry giants around the world hire hundreds, perhaps thousands of programmers to solve the technical problems of their production pipeline (Calude et al., 2014) and to invite more automated solutions. However, this dissertation thesis is not about streamlining approaches to increase **effectivity** - it aims to go beyond. Essentially, the thesis research explores the ways for small European studios to compete in an environment dominated by economic power-players who have hitherto been extremely effective in their CGI-AV creative outputs. The premise is that since the small studios do not have enough resources to compete through **effectivity** which is the time-tested approach by those biggest in the industry, the smaller players must seek the answer in **efficiency**. The aim is to introduce concrete delimitations to the abstract concept of **efficiency**, thus create implementable steps which would turn the quest for efficiency into a viable strategy.

7.3.1 Efficiency Formula Introduction

The thesis directly confronts the challenge of defining and measuring efficiency in CGI-AV production, a domain where artistic creativity intersects with technological advancement. Central to this inquiry are three pivotal research questions concerning the definition of **efficiency** and measurement of **quality** and **iteration**, representing both the theoretical underpinnings and practical applications of efficiency in the domain of CGI-AV. Building on the foundations of effectivity, the study addresses the ambiguity surrounding the concept of efficiency and systematically moves towards the quantification of efficiency in CGI-AV creation.

7.3.2 The Terms and Parameters

The following terms and parameters are used in the development of effectivity and efficiency formulas described in the subsequent chapter:

Parameter	Stands for	
E_{fe}	effectivity	
E_{fi}	efficiency	
S_k	artist skill	for the purposes of this work it is set as equal to 1 ³
	quantity of iterations⁴	through the whole project
	=	
I_t	project quality	the higher the quantity of iterations, the more the project improves as based on Catmull's premise
t_i	the time of one	individual iteration
	time spent	on the project (in all-persons days)
	=	
t_s	time of all iterations	time needed to create quality = accumulated times of individual iterations
	predicted time	spent on the project (in all-persons days)
	=	
t_p	budget	understood as budgetary restrictions
E_{fiT}	tool-formula	for efficiency

³ Quantifying artist skill is a problem for a separate course of research, requiring a different and deeper approach to quantification and is left as an open platform for further research. Hence, the artist skill value is kept as a constant in the formula, set as 1 for the purposes of this research; however, the theoretical aspect of this research opens up a discussion potential where the skill may range higher or lower than 1, without limitation.

⁴ In the tool-efficiency formula, that quantity is equal to 1.

7.3.3 From Effectivity⁵ to Efficiency⁶: The Formula Development

Arguably, the existing vast body of successful audio-visual creations is the testimony to the overall effectivity of CGI-AV creation thus far. Therefore, the thesis research considers effectivity to be a foundational aspect of the CGI-AV creation process, and a platform for launching the shift to efficiency. After determining the correlation between **quality** and **iteration**, the research turns to the relationship between **project quality** and **time spent** on the CGI-AV project as directly impacting the effectivity of that project. Inspired both by Ed Catmull's focus on enhancing the quality of CGI outputs at Pixar, and by the basic description of efficiency in physics, the initial concept for a formula was drafted, at first for determining effectivity:

$$[\text{Draft 1}] \text{ Effectivity} = \frac{\text{artist skill} \times \text{project quality}}{\text{time spent on project(creating quality)}}$$

Then, based on Catmull's claim that *'the movie steadily improves with each iteration, although sometimes a director becomes stuck, unable to address the feedback he or she is being given.'* (Catmull, 2014, p. 111) the formula was further developed by substituting quality for the number of iterations, on the basis of the above-described correlation between the two.

$$[\text{Draft 2}] \text{ Effectivity} = \frac{\text{artist skill} \times \text{quantity of iterations}}{\text{time spent on project}}$$

Thus, the formula proposes the calculation of **effectivity** (E_{fe}) as being equal to artist skill multiplied by the **quantity of iterations** (I_t) throughout the entire project divided by the **time spent** (t_s) on that project. The key aspect is the relationship between the '**time spent** (t_s) on the project' and the '**time (duration) of one individual iteration** (t_i)'. As long as the artist keeps iterating and increasing the quality of CGI-AV project, the 'times of individual iterations' continue to add up. When the project is finished, the iteration count stops. Thus, the **time of all iterations** (t_s) accumulated through the project is equal to the

⁵ Effectivity, or Effectiveness, stand for 'The quality of being successful in achieving what is wanted' (Cambridge University Press & Assessment, ©2024, p. 'Effectiveness')

⁶ Efficiency stands for 'The quality of working well in an organized way, without wasting time or energy' (Cambridge University Press & Assessment, ©2024, p. 'Efficiency')

parameter of **time spent on the project (t_s)**. Hence, due to this interrelation, both can be used interchangeably: **time spent on the project (t_s)** stands for the accumulated **time of all iterations (t_s)** and vice versa.

$$[\text{Draft 3}] \text{ Effectivity } (E_{fe}) = \frac{\text{artist skill } (S_k) \times \text{quantity of iterations } (I_t)}{\text{time spent on project } (t_s)}$$

The relationship between quality and iterations has been determined on the basis of the above discussed assertion by Catmull. The subsequent step is to introduce the relationship between the **project output** and the **quality (I_t)** as expressed by the quantity of iterations, as the indicator of efficiency. There are *two distinct approaches* to this, each with a different parameter:

First, there is the **subjective quality** of the CGI-AV output declared by the artist. By this reasoning, only the artist knows when the project is complete – until then, they keep **iterating**. However, this is already expressed in the above Draft 3 of the formula. Thus, it was established in the course of the research that this is an approach which would only calculate **effectivity (E_{fe})** – the accumulating use of resources to create quality. Hence, the first three drafts of the formula relate to effectivity and should be understood as the interim steps in the efficiency formula development.

There is, however, another possible parameter: the quality delivered under **budgetary restrictions**, whereby artists **iterate** until the budget is depleted. The budget is calculated in person-days. Thus, the budget of the project can be correlated with the **predicted time (t_p)** that will be spent on the project. Since it is a financially charged parameter, the **predicted time (t_p)** and its value (the project budget) need to be estimated as precisely as possible. It is the incorporation of the budgetary restrictions which transforms **effectivity (E_{fe})** into **efficiency (E_{fi})**.

This final step shifts the calculation from merely an **effective project** to an **efficient project**. Calculating efficiency includes the element where the **predicted time (t_p)** and the **time spent on project (t_s)** are described as a percentage of resources consumed in the project. Thus, efficiency increases when the percentage of consumed resources decreases.

$$\text{Efficiency } (E_{fi}) = \frac{\text{artist's skill } (S_k) \times \text{quantity of iterations } (I_t)}{\frac{\text{time spent on project } (t_s)}{\text{predicted time } (t_p)}}$$

From there, after math correction, the **complete formula for efficiency** was created.

$$E_{fi} = \frac{\text{artist's skill}(S_k) \times \text{quantity of iterations}(I_t) \times \text{predicted time}(t_p)}{\text{time spent on project } (t_s)}$$

$$E_{fi} = \frac{S_k \times I_t \times t_p}{t_s}$$

The formula covers the perspective of an efficient project or a viable concept or approach. The objective is to determine how artists can utilize their knowledge, resources and skills to adhere to deadlines and time schedules, which are fundamental to efficient approaches in CGI-AV creation. Thus, the **efficiency formula** presents an answer to the first research question of how to calculate efficiency of the CGI-AV creation process, or assess the efficiency of a creator's approach. Hence, its utilization as a guiding principle can assist creators in practical planning of budget and schedules. Furthermore, the formula serves as platform for an application of its simplified version as an efficient tool.

7.3.4 Tool-formula for Efficiency

Because small CGI-AV studios and freelancers do not have enough resources to compete through effectivity alone, it would benefit them to seek an answer in **efficiency**. With lower resources available to them, they can instead approach the creation of high-quality CGI-AV outputs through efficiency mindset. This extends to transforming hitherto effective tools to efficient ones. Thus, while effectivity in itself is the domain of the big CGI-AV studios, effectivity in tandem with an efficiency mindset can become a guiding principle and a practical tool of the small studios and freelancers.

The idea here was to further develop a ‘tool-formula for efficiency’ which can aid CGI-AV creators in identifying the most efficient software tools that will promote rapid iteration - yet again with reference to Catmull’s claim that the *,movie steadily improves with each iteration.*’ The relationship of quality and iteration was the key informing element here, since the selection of efficient software is determined by its utmost utility for a given task, thus supporting the most efficient iterative process. Hence, the base for the tool-formula came from the effectivity formula (draft 3 above, where there is no parameter of budgetary restrictions, since that factor does not contribute to the tool-formula calculative purpose).

$$\text{Effectivity } (E_{fe}) = \frac{\text{artist skill } (S_k) \times \text{quantity of iterations}(I_t)}{\text{time spent on project } (t_s)}$$

The logic of the tool-formula is to provide artists with the best possible intuitive experience of its usage. Thus, from the perspective of gaging the efficiency of a software solution, the tool-formula had to be computer-precise, therefore streamlined to facilitate the mechanical aspect of CGI-AV creation. Thus, the subsequent step was to reduce the formula by the artist skill parameter.

$$\text{Tool – formula for Efficiency } (E_{fiT}) = \frac{\text{quantity of iterations } (I_t)}{\text{time spent on project } (t_s)}$$

The next step is the idea of intuitive application of the tool-formula to/within a project, whereby it has to be universal to every project, and every artist. The term project is understood here as a spacetime of the artist utilizes software tools to create a specific CGI-AV output, where the meeting of the artistic and technical should be conducted with utmost efficiency, as posited by the research question 4.3.10 For the universal applicability of the tool-formula to every project, the parameter of **time spent on the project** (t_s) was replaced with its equivalent thus interchangeable parameter **time of all iterations** (t_s), which is better suitable to the technical context of the tool solution.

$$\text{Tool – formula } (E_{fiT}) = \frac{\text{quantity of iterations } (I_t)}{\text{time of all iterations } (t_s)}$$

The final step is removing the quantifiers, because the formula can be repeated for and applied to every iteration.

$$\text{Tool – formula } (E_{fiT}) = \frac{\text{iteration } (I_t)}{\text{time of iteration } (t_i)}$$

The reduced formula presents the basic technical concept of effectivity, understood as the relationship between **an individual iteration** (I_t) and **the time of this individual iteration** (t_i). However, the formula application itself is driven by an efficiency mindset: the artist uses it to streamline a range of software choices to the one that intersects suitability for the given task with efficient facilitation of the most rapid iteration possible. Therefore, the more rapid its iteration capability, the more efficient the software tool would be, with the ideal tool being capable of previewing any changes to a given project phase in real time. Arguably, the tool-formula does not include the parameter which computes the resources spent on the project or creation, and it is therefore rooted in effectivity. Nevertheless, the mindset behind the actual tool-formula utilization would always already be embracing efficiency rather than just effectivity, since the very purpose of the tool-formula usage is to find the best software solution for making rapid iteration at the lowest possible expenditure of resources, including on the development of that solution.

$$E_{fit} = \frac{I_t}{t_i}$$

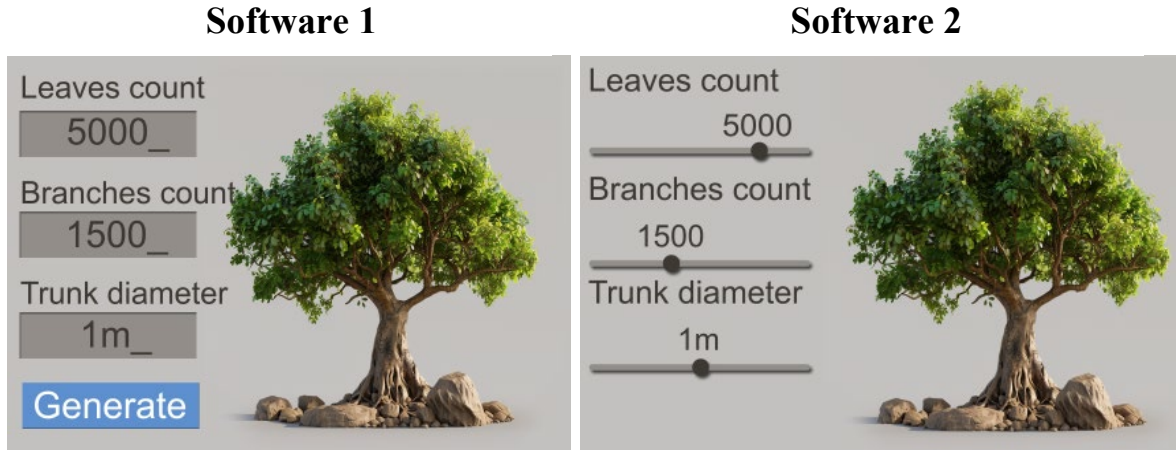


Fig. 7.1 The tree example.

The practical application of the tool-formula as an efficiency filter aiding software selection can be demonstrated on the tree example in the Fig. 7.2. If a CGI-AV artist needs to create a tree, there are various software solutions available to them, offering different paths to achieve the goal. If the efficiency mindset rooted in the tool-formula is applied, it will quickly be clear that the best choice is the software which enables the most rapid iteration. Such software would allow the artist to see the results of their process instantly, hence speeding up the subsequent changes and iterations that lead to the increasing quality of the final result – here, a CGI tree. The tree example explains the time of one iteration (t_i) by two different software solutions. The image on the left represents the software version where the user adds the parameters, uses the ‘generate’ button, and only after that they will be able to see the results. Those results will then have to be adjusted over and over again, until the desired quality is achieved. On the other hand, the right image represents a software situation where the user uses sliders and interactive GUI: the changes, thus iteration, are instant, reviewed after the change by the slider. Here, the increasing quality of the output is created much more rapidly, hence efficiently, than with the first software - therefore allowing the artist to move onto other tasks and remain in the creative flow. Thus, the tree example showcases a software selection where the choice, informed by the efficiency mindset and tool-formula expressing the ratio of the individual iteration (I_t) and the time of this individual iteration (t_i), significantly increases the artist’s efficiency. With the use of the first software, it may take an artist about 5 to 10 iterations, depending on their skill, with each iteration taking some time to adjust the parameters and generate a newly updated image. In contrast, the second

software enables instant review and adjustment. Accumulation of these creative situations is directly reflected in person-hours expended on the project, whereby efficiency is driven by the use of software that reduces person-hours while delivering high quality outputs. Furthermore, the first software is not only much slower in enabling rapid outputs, but also favours a specialist and/or experienced artistic skillset for making a more accurate first input (i.e. closer to the desired result), than an inexperienced artist who would need more iterations in time. However, with the seconds software, a generalist or a less experienced artist would be quicker achieve a quality result due to the instant reviewing process.

Thus, an artist who needs to select a suitable software tool for a particular aspect of the creation can apply the tool-formula as an efficiency mindset and a selection filter, whereby the ideal software enables **unlimited iterations instantaneously**. This concept, supports the premise of the future possibility of a pipeline that theoretically permits iteration throughout the entire project in real-time, promoting a progressive strategy for maximizing efficiency and productivity in CGI-AV creation. However, it is indisputable that artists, software solutions and projects much differ from studio to studio or freelancer. It is also expected that, regardless of its long-term benefits in resource saving and profitability, it might be challenging to foster an intuitive efficiency driven and tool-formula facilitated approach to CGI-AV creation both across company cultures and individual mindsets. Therefore, this approach, consisting of the efficiency filter and the utilisation of the tool-formula for efficiency, was translated into comprehensive **guidelines**, where the question of resources plays a crucial role.

7.3.5 Efficiency Formula as a Viability Determinant

The efficiency formula
$$E_{fiT} = \frac{Sk \times It \times tp}{ts}$$

goes beyond being merely a mathematical or measurable attribute of an efficient approach; it serves as a guiding principle for **determining the viability** of a CGI-AV project, thus providing a tool for business strategy. Furthermore, it can also aid retrospective evaluation of a project's efficiency, hence providing a valuable analytical function. The efficiency formula accounts for scenarios where highly experienced experts require only a single iteration because of their high skill. In such cases, if the time predicted and the actual time spent on the project align precisely, the efficiency should match that of an artist with lesser skill who requires more iterations. The premise indicates that it is possible to achieve the same quality CGI-AV output even with less skill, providing enough iterations are made. However, how can the less skill / more iterations scenario be understood in terms of achieving efficiency, or, in other words, commercial viability? This is where the efficiency formula suggests an answer based on the relationship

between time and iteration. Traditionally, iterations in linear pipelines are resource and time consuming, with iteration time based on rigid sequences of technical processes. However, if time of iteration can be condensed, the higher quantity of iterations will not have a negative impact on efficiency. Hence, the theoretical solution lies in a technological solution, i.e. software that enables faster iterations, thus condensing the iterative process and potentially driving an increase in quality.

7.3.6 Conclusion

Arguably those two approaches – the efficiency formula for determining the viability of a project and the tool-formula for determining efficient software seem to differ each other, but the difference is superficial, as they are both firmly rooted in the efficiency mindset. However, to complete the full picture of the efficiency implementation proposal, it is necessary to address one more factor: the workflow organization of the CGI-AV creation process.

7.4 Art-Nodes

By seeking to engage with both the technological and artistic, this thesis' search for efficiency is firmly grounded in an exploratory transdisciplinary discussion, resulting in innovative recombinations and fresh perceptions of the artist's role and position within the highly technical process of CGI-AV creation. In this context, the research proposes a new territory by introducing of the concept of art-nodes. The term 'art-node' itself was coined by the author to denote a novel approach to handling the areas of artistic I/O within the CGI-AV workflow. The present chapter will outline and explain art-nodes in terms of their premise, organization and functionality.

In the space-time of CGI-AV linear pipeline creation, there are numerous checkpoints for assessing the artistic inputs. For instance, when integrating a 3D character into live-action footage, there are 32 artistic inputs at which an artist or director must subjectively evaluate the project's quality. Furthermore, each of these 32 inputs requires subsequent separate iterations before one iteration across the whole project is made.

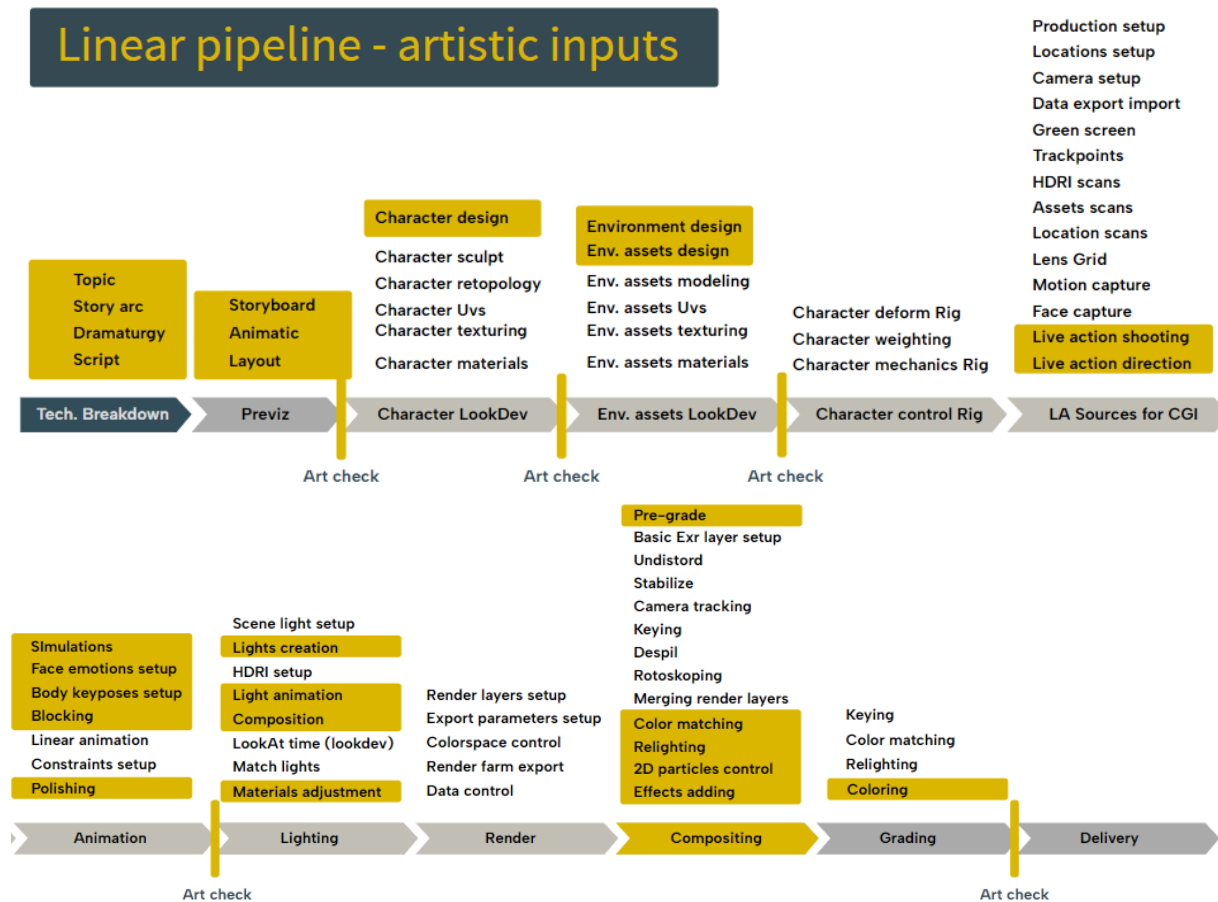


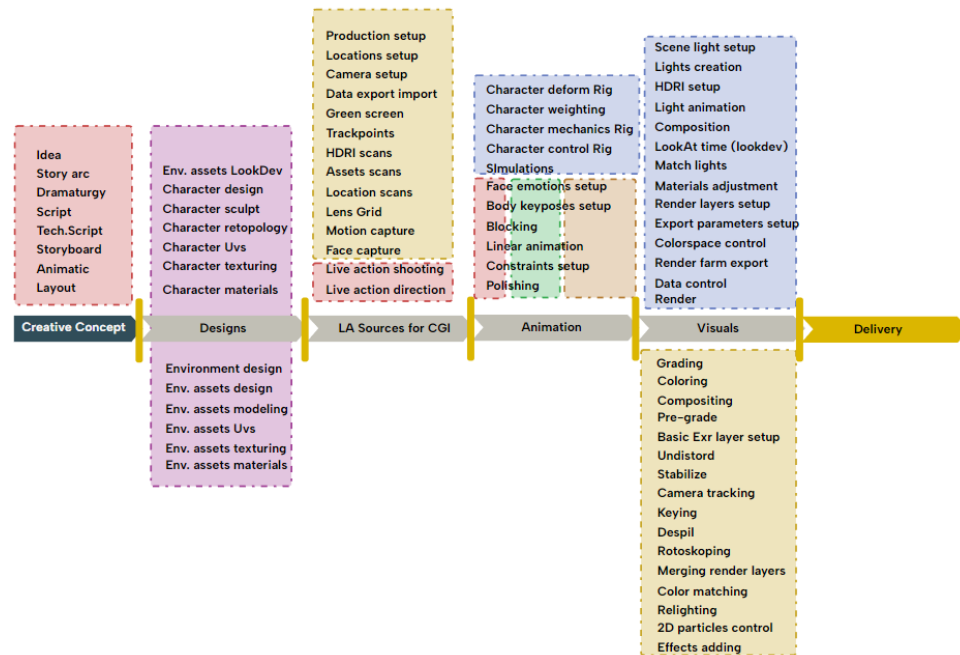
Fig. 7.2 Linear pipeline's artistic control checks

To increase efficiency, it is essential to streamline these numerous inputs to speed up the iterative process throughout the project. To enable rapid iteration, the thesis proposes to radically streamline those 32 artistic inputs into 5 core creative stages, henceforth termed **art-nodes**, whose organization is informed by the minimal viable generalist⁷ skill scope within the stages. This consolidation of artistic inputs into 5 art-nodes relies on modern hardware power and procedural setups that facilitate communication or generation of asset parts based on artistic inputs. The tools that would enable this efficient transformation are procedural production software such as *Houdini*, *Blender* with its geometry nodes, *Unreal Engine* etc.

⁷ *Generalists* have a broad, versatile and flexible skillset and mindset, which can quickly adapt to changing project demands and technological options.

The five art-nodes are:

- (1) Creative Concept (Idea and Story)
- (2) Designs and Concept Arts
- (3) Live Action Shooting (LA Sources for CGI)
- (4) Animation
- (5) Visuals (Lighting-Compositing-Grading)



Generalist skill scope

- Director / Art lead / Animator
- Tech. Director / Rigger / Pipeline TD / Lighter / Technical artist / Simulations
- Char. Designer / full stack designer
- Animation Lead / Animator / Rigging assistant
- VFX Supervisor 1 / Lighting
- Animator 2

Fig. 7.3 Condensing artistic inputs into five distinct art-nodes signifies a vertical segmentation of CGI-AV creation stages.

The term art-node synthesizes these creative stages with the tools required for each, aiming to maximize the artists' time spent in the art-flow and minimize their technical micro-tasking. In essence, **art-node is defined as the space-time where artists can engage in smooth creation facilitated by immediate access to all necessary digital tools**. Thus, the concept of art-nodes both enables and streamlines smooth interaction between the technical and the artistic. In addition, art-nodes serve as control points in the increasingly popular field of machine learning systems, known as AI tools.

The practices facilitated by art-nodes are informed by efficiency driven approaches which embrace automation and procedurality to support a more

efficient iterative process, thus contribute to the increase of the project's quality while reducing the time spent on the project. This objective is firmly grounded in the anticipation of practical implementation and utilization of the art-nodes within the overarching concept of non-linear pipeline for CGI-AV creation.

7.5 APPLIED PROCEDURALITY AND AUTOMATION

A deliberate application of procedurality and automation in the context of a non-linear pipeline mindset maximises their potential as the agents of efficiency. These components work together to establish the foundation of non-linear pipeline, enabling artists to create dynamic, interconnected structures that defy linear progression and respond adaptively to user inputs or predefined conditions.

7.6 GUIDELINES TO IMPROVE EFFICIENCY

Drawing together the progressive aspects of the research, the reasoning behind the efficiency mindset and the tool-formula is translated into guidelines, deemed more suited for application in the artistic domain. The guidelines serve as a series of principles for identifying the most efficient approaches both for new projects and for retrospective analysis of completed projects.

The Efficiency Guidelines:

- (1) Rapid iteration: aiming for the capability of real-time processing.
- (2) Focus on art-nodes to ensure efficient workflow.
- (3) Ensuring clean outputs from art-nodes for streamlined technical processes of communication.
- (4) Maximizing automation, including a wide range of one-click tools in art-nodes.
- (5) Promoting the recycling of CGI-AV project components for future use.
- (6) Establishing unambiguous communication channels (drawing, text, video) among the creative team in real-time.
- (7) Promoting real-time and on-demand team cooperation.

7.7 THE CONCEPT OF NON-LINEAR CGI-AV PIPELINE

Since there is no single solution that integrates every aspect of efficiency as outlined in the guidelines, this dissertation proposes a theoretical framework for non-linear pipeline which would combine art-nodes centered procedurality and automation with every tool an artist might need ready for use in real time, enabling flexible functionality thus positively impacting the efficiency, speed, control and precision of the creative process.



Fig. 7.4 Blueprint of non-linear pipeline

7.7.1 Blueprint of Non-Linear Pipeline with Existing Technology

The following parameters can be used as blueprint for creating a custom non-linear pipeline. The blueprint of non-linear pipeline is a combination of existing software solution elements and parameters.

The Non-Linear Pipeline Parameters:

- (1) Timeline as review controller
- (2) Server based version control system
- (3) Generators (procedural assets)
- (4) Asset managers
- (5) In screen annotations
- (6) Team project creation

There is not yet an all-in-one non-linear software solution on the market which would cover all the six above listed technical parameters, hence the blueprint solution, for now, has to propose a combination of several. However, the software solutions combination itself varies from studio to studio and their capability of reaching the non-linear pipeline parameters for efficiency has to be assessed individually by the user needs.

7.8 CONCLUSION OF THEORETICAL PART

The theoretical section develops a method for defining efficiency through the efficiency formula, tool-formula and efficiency mindset. Thereby, it proposes the guidelines for determining the most efficient set of procedures, creation tools and workflow practices for CGI-AV creation, ultimately resulting in the concept of Non-Linear CGI-AV Pipeline.

8. EXPERIMENTAL PART – QUANTIFYING ITERATIONS

The experiments concern a key term and a cornerstone of this dissertation – **iteration**, as a fundamental contributing factor of the efficiency formula. The experiments use two distinct approaches to computing iteration, purporting to prove that iteration can be identified and quantified.

The first approach involves a universal method of quantifying iterations through the image comparison of the stages of the CGI-AV creation process, with several ways of execution. Thus, this experimental section examines and utilizes a range of **image difference methods**.

The second approach is more precise, and focuses on the aspect of CGI-AV creation involving timelines and sequences of images, which is of utmost relevance to the CGI-AV industry field addressed by this research. Here, the experiment presents a custom-made **timeline iteration quantifying method**.

For these experiments to take place, it was first necessary to obtain data on the human perspective on perceiving differences in the stages of CGI-AV creation to establish a basic reference point for the comparison with the machine calculations of image differences. Thus, as an original experiment in its own right, a **quantitative survey for image comparison** was developed to collect the data that would underpin the next steps of the research.

8.1 IMAGE DIFFERENCE METHODS

The premise for the application of Image difference methods is that measuring the size of iteration is the same as measuring the difference between images, whereby the software user then decides which size of difference is enough to constitute a finished iteration which can be quantified. The ability to measure the size of iteration is a bonus, and theoretically can lead to further research on how the size of iteration impacts the project's quality after that iteration.

The findings:

Average Mean Human	0,84	0,72	0,81	0,50	0,08	0,14	0,09	0,78	0,69	0,85	0,18	0,91	0,71	0,20	0,15	0,85	0,81	0,10	0,27
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Tab. 8.1 Image comparison survey normalized outputs

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Deep AI	8	6	10	12	12	10	2	18	38	30	10	14	16	12	6	34	32	8	8
Structural Similarity Index	0,82	0,93	0,65	0,71	0,49	0,82	0,96	0,63	0,37	0,35	0,91	0,91	0,86	0,86	0,82	0,74	0,68	0,91	0,88
Histogram Diff	0,90	0,93	0,58	0,76	0,66	0,63	0,92	0,69	0,47	0,20	0,67	0,95	0,83	0,74	0,93	0,05	0,30	0,53	0,50
Peak Signal To Noise Ratio	0,59	0,47	0,71	0,66	0,67	0,57	0,44	0,63	0,86	0,80	0,60	0,60	0,66	0,62	0,67	0,76	0,74	0,56	0,70

Tab. 8.2 Direct results of image difference methods

Deep AI	0,22	0,04	0,56	0,86	0,86	0,56	0,09	0,45	0,92	0,79	0,23	0,70	0,86	0,50	0,05	0,86	0,82	0,16	0,16
Structural Similarity Index	0,71	0,92	0,26	0,42	0,04	0,73	0,89	0,48	0,14	0,13	0,85	0,93	0,47	0,49	0,09	0,26	0,10	0,87	0,79
Histogram Diff	0,12	0,08	0,90	0,44	0,73	0,80	0,08	0,35	0,69	0,95	0,37	0,14	0,66	0,93	0,22	0,94	0,59	0,17	0,21
Peak Signal To Noise Ratio	0,40	0,04	0,89	0,74	0,75	0,30	0,07	0,42	0,90	0,81	0,32	0,08	0,82	0,31	0,83	0,82	0,72	0,05	0,56
1 - Structural Similarity Index	0,29	0,08	0,74	0,58	0,96	0,27	0,11	0,52	0,86	0,87	0,15	0,07	0,53	0,51	0,91	0,74	0,90	0,13	0,21

Tab. 8.3 Normalized results of the image difference methods

Error

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Deep AI	0,62	0,67	0,24	0,36	0,79	0,42	0,00	0,33	0,23	0,07	0,05	0,21	0,15	0,30	0,09	0,01	0,01	0,06	0,11
Structural Similarity Index	0,13	0,20	0,54	0,08	0,03	0,59	0,81	0,29	0,55	0,73	0,66	0,02	0,24	0,29	0,06	0,59	0,71	0,77	0,52
1 - Structural Similarity Index	0,56	0,63	0,07	0,08	0,88	0,13	0,02	0,26	0,17	0,02	0,03	0,84	0,19	0,31	0,77	0,11	0,09	0,03	0,06
Histogram Diff	0,72	0,63	0,09	0,06	0,65	0,67	0,00	0,43	0,01	0,09	0,19	0,77	0,05	0,73	0,07	0,09	0,22	0,07	0,06
Peak Signal To Noise Ratio	0,44	0,68	0,08	0,24	0,68	0,16	0,02	0,36	0,22	0,04	0,14	0,83	0,11	0,11	0,69	0,03	0,08	0,05	0,29

Tab. 8.4 Error from the existing computation techniques

train data 1 - 19			test pairs	
	Sum err	avg err	20	21
Deep AI	4,74	0,25	0,29	0,15
Structural Similarity Index	7,81	0,41	0,25	0,13
1 - Structural Similarity Index	5,25	0,28	0,74	0,37
Histogram Diff	5,60	0,29	0,32	0,16
Peak Signal To Noise Ratio	5,25	0,28	0,76	0,38

Tab. 8.5 Error comparison between image difference methods

Image difference methods such as *Hellinger Histogram*, *SSIM* and *PSNR* represent the computation techniques, defining the spectrum of the research scope from the simplest form of the image difference to an intermediate one. The most complex image difference

technique represents the *Deep AI*. Furthermore. A custom-made Linear regression method based on the four components of the image also formed part of the experiment.

Image Difference Comparison Results:

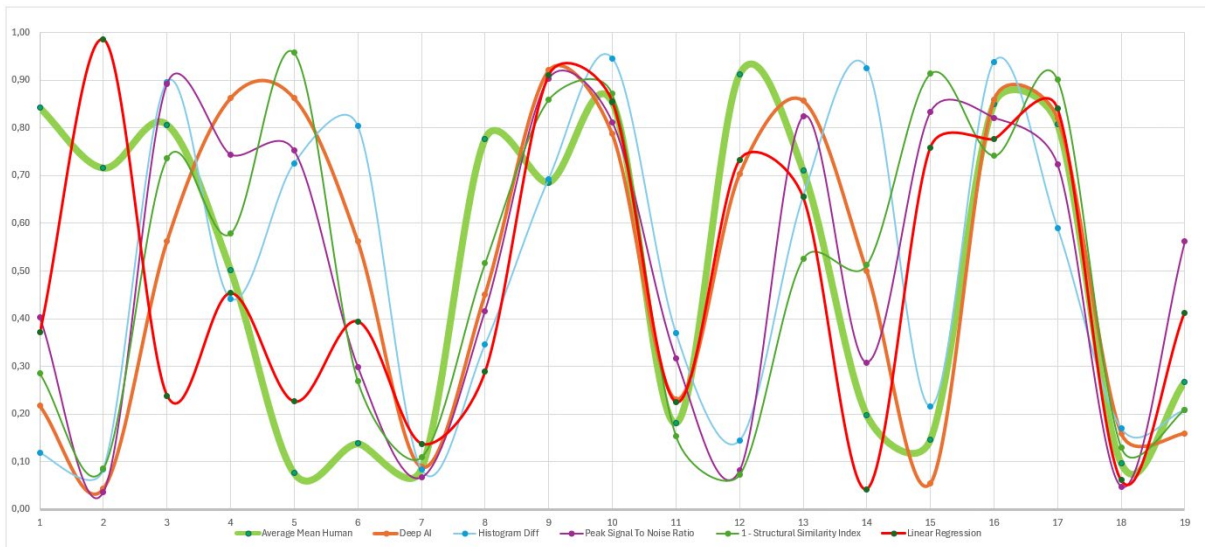


Fig. 8.1 The error of all the image comparison methods compared with the human respondents' data.

8.2 READING TIMELINE CHECKED FRAMES

The timeline-checked frames method offers a precise measurement technique for identification and quantification of iterations. However, unlike image comparison which is universal, it is limited to timelines, meaning it is applicable only to image sequences. Regarding the creation of this method, a custom code was developed for reading viewed frames, based on the efficiency formula⁸ developed in the theoretical part of this thesis. Reading timeline checked frames is the method whose outputs - the quantity of iterations and time spent in the project - are the main parameters to the efficiency formula. Those parameters are delivered by the custom plugin for Premiere Pro based on the premise that an iteration is a review of the whole project with an adjustment.

8.3 MACHINE ITERATION

The ability to identify and quantify iterations through an automatic computer calculation is crucial to the progress of the research, expressed in the research question ‘Can iterations be quantified?’. The experimental part explored two possible paths to quantifying iterations, whereby both paths provide the confirmation that **iterations can be quantified**.

⁸ Efficiency formula: $E_{fi} = \frac{s_k \times l_t \times t_p}{t_s}$

9. PRACTICAL PART

The practical part presents a series of case studies of actual CGI-AV projects made between 2014 and 2023. As the VFX supervisor on these projects, the author of this dissertation thesis possesses access and deep insight into their complex workings, practical solutions and organizational challenges. Retrospectively applied, the parameters and guidelines were aligned with the corresponding elements of the projects and evaluated on those practical situations, charting the transformations and shifts in the projects where they were progressively implemented. The resulting evidence validates the premise that through even elements of the non-linear approach, a significant improvement in speed and quality can be achieved, confirming the practical relevance of the efficiency guidelines in real-world application.

The practical part further assess the applicability of existing software solutions to the non-linear pipeline parameters. This approach enables the integration of the non-linear pipeline approach with current software tools, and informs the future development of a bespoke all-in-one software. This custom software would efficiently aggregate the efficiency guidelines principles under a unified system.

10. RESULTS

Efficiency of Creation in Digital Audiovisuals

The Concept of Non-Linear CGI-AV Pipeline

10.1 PRIMARY GOAL RESULTS

10.1.1 Research, Experiments and Theory

The progressive results of the research, experiments and theory of **Efficiency of Creation in Digital Audiovisuals**, corresponding with the primary research goals:

- Current industry state was evaluated and positives and negatives were identified.
- Question of quality was examined and correlated with rapid iteration.
- Iteration was determined as crucial to efficiency in CGI-AV creation.
- Iteration quantification was proven to work through a series of experiments.
- Two formulas that underpin the application of efficiency were determined:

$$E_{fi} = \frac{S_k \times It \times t_p}{t_s}, \quad E_{fiT} = \frac{It}{t_i}$$

10.1.2 Conceptualization and Application of Non-linear CGI-AV Pipeline

The creation and application of the **Concept of Non-linear CGI-AV Pipeline** as the resulting output of the primary research goals:

- CGI-AV creation workflow was reconceptualized: creative stages were consolidated as art-nodes connected by procedurality and automation; thus, an organizational base for non-linear pipeline was established.
- Guidelines for efficiency were created, based on the above formulas.
- Blueprint of non-linear pipeline with existing technology was established and its elements and parameters were determined.
- Existing CGI-AV projects, created under the thesis author's VFX supervision, were analysed alongside the non-linear pipeline blueprint parameters and efficiency guidelines. The analysis results validated the premise that efficiency of creation increased with increased application of

the parameters and guidelines - in other words, the more the projects adhered to them, the higher efficiency they achieved.

- The finding from the practical projects were then reversely applied to the existing software solutions, whose applicability was assessed on the basis of their utility to a) the whole non-linear pipeline, and b) the individual art-nodes as projects. (see 9.7)

The **Concept of Non-linear CGI-AV Pipeline** was established, with two potential future paths:

- An immediately applicable **blueprint of non-linear GCI-AV pipeline** using existing software solutions
- A theoretical platform for the future development of an **all-in-one non-linear CGI-AV pipeline** software solution.

10.2 SECONDARY GOAL RESULTS

Holding the geo-economical stance of small European studios and freelancers⁹ to help them gain competitive advantage, the thesis results in conceptualizing an immediately applicable **blueprint of non-linear GCI-AV pipeline** using existing software solutions. Since small studios have limited resources at their disposal, they need to deploy **efficiency as a strategic tool** for creating high quality CGI-AV outputs that can withstand the competition of large industry players.

10.2.1 The Artist: Efficient CGI-AV Production

Efficient CGI-AV production is a premise achievable by the deployment of the **non-linear pipeline blueprint**, where even a partial application of some of its elements and parameters benefits small teams and freelancers.

The resulting benefits for the Artists:

- Minimized steps of the production process through consolidating creative checks into art-nodes which enable simultaneous real-time creation and revision.
- Removal of excessive technical tasking to support creative art-flow, freeing more time for artistic experimentation and increasing output quality.
- Creative collaborative environment where, within and between the different art-nodes, artists communicate and work parallel with each other, sharing ideas, expertise, and resources.
- Promotion of generalist mindset for broader skill range, thus enhancing professional competence and adaptability to future challenges such as AI or senior CGI-AV expert exodus. Potential for some generalists to evolve into specialists in the art-node field.
- Efficiency-driven mindset for individual freelance CGI-AV artists, whose work may be optimized to such extent that it takes on the characteristics of a one-person team.
- Rapid iteration: non-linear pipeline promotes rapid iteration processes, enabling artists to quickly test and refine their creations and prototypes. Artists can identify flaws, gather feedback, re-evaluate and make improvements more swiftly, ultimately resulting in better, more polished

⁹ The following outputs are based on the premise of freelancers being a small team in themselves (a one-person-team), where the small team has only the additional parameter of establishing parallel creation in art-nodes and communication channels.

outputs. Rapid iteration with the non-linear pipeline helps to streamline the design process and foster innovation.

10.2.2 Prototyping: Strategies for Efficiency

Utilizing non-linear pipeline in the creative process offers unique opportunities for efficient prototyping. Prototyping is highly speculative and very risky, since there is no guarantee that the invested resources will be recovered, yet demands a great deal of resource-consuming innovative experimentation. This, especially for small studios and freelancers, can have a serious economic impact, while on the other hand, a successful prototype increases the studio's marketplace and competitive ability. By embracing the flexibility and adaptability inherent in the non-linear pipeline, artists and designers can experiment, iterate, and refine their prototypes rapidly and with lower resource expenditure, thus more efficiently. Thus, fast and high-quality prototype production can increase the creator's chances of success in the CGI-AV economics, by giving them the ability to pitch and tender a greater number of projects at open calls and trade fairs.

The key strategies for efficient prototyping are:

Parallel exploration, where multiple ideas can be pursued simultaneously, allowing for the parallel exploration of different concepts and designs.

Procedural design which allows for greater flexibility in incorporating feedback, making adjustments, and swapping components as needed.

Rapid iteration, key to successful experimentation which drives both creativity and quality.

Collaborative environment enables team members to work on different aspects of a prototype simultaneously, and by promoting real-time and on-demand team cooperation.

10.2.3 Economics: Non-Linear vs. Linear Pipeline

Linear pipelines are mostly designed for the priorities of the sales end, while the non-linear pipeline is designed to support the artist in creating quality output in a shorter space of time, thus reclaiming sales advantage through the ratio of the time spent on the project and the time predicted (the budget for the client), hence enhancing the small studios and freelancers' competitive advantage.

The linear pipeline monetizes its outputs a) by **effectively** delivering the CGI-AV product to the client, and/or b) by motivating the client to require extra work on the project, where in iterating, it is literally re-creating - through 32 heavily resource-consuming art checks (at often unnecessary extra expense to the client). In contrast, the non-linear pipeline monetizes its outputs a) by **efficiently** delivering the CGI-AV product (i.e. achieving higher quality in less time), and/or

b) by the ability to re-allocate the resources saved by rapid iteration within just 5 art-nodes (benefitting both the creator and the client, due to the potential of more favourable pricing conditions). Calculating efficiency includes the element where the predicted time (t_p) and the time spent on project (t_s) are described as a percentage of resources consumed in the project. Thus, efficiency increases when the percentage of consumed resources decreases.

$$E_{fi} = \frac{S_k \times I_t \times t_p}{t_s}$$

11. CONTRIBUTION OF THE DISSERTATION WORK

This dissertation thesis contributes to science and practice with a series of tangible outputs. Transdisciplinary in scope and experimental in nature, it presents a broad range of scientific research findings and practical outcomes applicable in the real-world scenarios.

11.1 PRESENT CONTRIBUTION

The dissertation presents the following contributions to the advancement of the CGI-AV field, through the theoretical and practical application:

- Comprehensive overview and evaluation of the contemporary situation in the CGI-AV industry.
- Discovery of the relationship between quality, iteration and efficiency.
- The determination of the concept of iteration, as a ‘a systematic revision of the current phase of a creative project across that entire project’ (see 7.2).
- Identification and quantification of iterations – creation of original replicable methodology to aid in digital audiovisual production.
- Formula-based practical guidelines to increase efficiency for small creative teams and freelancers, where the formulas support replicable and universally applicable procedures.
- An immediately applicable **blueprint of non-linear GCI-AV pipeline** using existing software solutions, with the parameters supporting the creation of custom non-linear pipelines based on individual user requirements.
- Applicability assessment and recommendation of existing software suited to the non-linear pipeline parameters.
- A theoretical platform for the future development of an **all-in-one non-linear CGI-AV pipeline** software solution.

11.2 FURTHER RESEARCH PLATFORMS

The present dissertation research opened several platforms for potential further course of research and development:

- Determining **Artist Skill in GCI-AV** creation. Artist Skill is one of the values of the effectivity formula created by the present research. Its value here is set as 1, however, more research into artist skill in CGI-AV could lead to further evaluation, determination and quantification.

- Further application of *Reading Timeline Checked Frames* approach. Future research could potentially adapt this system to static images, focusing on specific areas of interest and zoom levels. This adaptation could mirror the process of checking frames in a timeline, providing a comparable level of detail and precision in different visual contexts.
- The **measurement of the size of iteration**, potentially as the contributor to the subsequent quality increase or decrease. While the present research stopped with the achieved objectives of identifying and quantifying iteration, there still remains much unexplored research territory in approaches to measurement and precision refinement.

11.3 FUTURE PLANS

The theoretical platform for the future development of an **all-in-one non-linear CGI-AV pipeline** software solution remains a potentiality. The author's future plan is to further pursue its development, eventually delivering a functional, market-viable product which will serve its users in delivering quality CGI-AV at a fragment of the current resource expenditure.

In addition, the author is interested in a new opportunity that the present research has brought up – namely the potentiality of the machine learning tools in the non-linear pipeline, where there could be a gap between controllable inputs and quality outputs. Thus, the future aim is to find ways to maximize the potential of the machine learning tool usage in art-nodes to further benefit the artist.

12. CONCLUSION OF THE DISSERTATION WORK

Introducing an innovative method for calculating and implementing efficiency within the CGI-AV artistic environment, the thesis delivers the **concept of non-linear pipeline** to promote a synergic relationship between the technical options and artistic I/Os. The predominant aim for the practical outcome is to deliver a solution which would enhance the efficiency of CGI-AV freelancers, small teams and studios, in order to support their market position and competitive edge from the geo-economic aspect of the Central-European marketplace.

The thesis argues for a shift from traditional linear methodologies, which are rooted in the analogue film technologies, **to a non-linear pipeline that enhances artistic freedom by automating the technical aspects of creation**. This transition aims to reduce the number of creative checkpoints significantly, from 32 to 5 art-nodes, thereby streamlining the production process. The non-linear pipeline concept consists of guidelines for application, a blueprint of parameters, and existing software applicability recommendations. The blueprint can be flexibly applied to the needs of diverse-sized creative teams, and furthermore aid the efficiency of pilot creation as the means of gaining competitive advantage in the global CGI-AV industry context. Additionally, addressing the future potentiality, the thesis looks towards the theoretical possibility of an all-in-one software solution to drive the efficiency of CGI-AV creation.

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14. LIST OF USED FIGURES AND TABLES

14.1 FIGURES

<i>Fig. 6.1 Linear pipeline of the injection of CGI elements into live action footage</i>	14
Fig. 6.8 Linear pipeline's artistic control checks.....	14
Fig. 7.2 The tree example.....	23
Fig. 7.3 Linear pipeline's artistic control checks.....	26
Fig. 7.4 Condensing artistic inputs into five distinct art-nodes signifies a vertical segmentation of CGI-AV creation stages.	27
Fig. 7.6 Blueprint of non-linear pipeline	29
Fig. 8.19 The error of all the image comparison methods compared with the human respondents' data.....	32

14.2 TABLES

Tab. 8.2 Image comparison survey normalized outputs	31
Tab. 8.3 Direct results of image difference methods	31
Tab. 8.4 Normalized results of the image difference methods	32
Tab. 8.5 Error from the existing computation techniques	32
Tab. 8.6 Error comparison between image difference methods	32

15. LIST OF USED AUDIOVISUAL WORKS

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Stream – Mrazivá Tajemství: <https://www.stream.cz/mraziva-tajemstvi>

MALL – Vánoce 2020: <https://youtu.be/J2wGvypyNEc>

MALL – Vánoce 2022: <https://youtu.be/KrrTWcQSOCs>

16. PROFESSIONAL BIOGRAPHY

Marcel Legindi was born in 1987 in Český Těšín, Czech Republic. In 2017, he earned his Master Degree in Audiovisual Arts from Tomas Bata University in Zlín. Now a Ph.D. candidate and a lecturer in the field of 3D Graphics at the same university, his passion for streamlining the CGI creation process informs his research focus on efficiency in the field of CGI-AV creation. With the background in computer graphics and automation, in 2014, Marcel founded the BBP studio where he has since been serving as the Technical Director. Possessing nearly 20 years of experience in the industry, Marcel has cultivated a diverse skill set, positioning himself as a versatile CGI generalist. His background spans various aspects of computer graphics and animation, enabling him to address a wide range of challenges with ingenuity and expertise. As he continues to advance both academically and professionally, Marcel remains committed to pushing the boundaries of CGI technology and is dedicated to automating every possible technical task in the field.