Studiengang Informatik

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Bachelor Thesis

to the subject

Analysis of procedural Materials

within Fragment-Shader

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**Statutory Declaration**

I hereby declare, that the present thesis was written and developed self-reliant and under exclusive use of the stated literature and resources. The thesis was not submitted in the same or similar form or in extracts to any testing authority yet.

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# 1 Introduction

Procedural texturing always has been a subject in computer graphics. Researchers sought for algorithms and improvements to synthesize textures to represent natural looking surfaces. Early algorithms like Perlin-Noise [(P01)] or Worley-Noise [(W01)] are still present today and essential for procedural generations, due to their natural looking appearance which suits replicating natural surface properties.



*> [Figure01] Images from early papers; Left: Perlin noise [(P01)]; Right: Worley noise [(W01)]*

Today, "With the ever increasing levels of performance for programmable shading in GPU architectures, hardware accelerated procedural texturing in GLSL is now becoming quite useful[...]" [(G01)], because "[...] modern shader-capable GPUs are mature enough to render procedural patterns at fully interactive speeds [...]" [(G01)]. Which enables essential algorithms types for procedural pattern generation like noise or distance fields to be used as implicit implementation in shaders, because shaders will query for information about arbitrary points, set by the current pixel distribution.

Today, a variety of modern 3D applications like "Blender" [(BLE01)], "Unity 3D" [(UNI01)], "Unreal Engine" [(UNR01)] or "Cinema 4D" [(CIN01)] offering interfaces to attached renderers to handle the shading of objects in a modular manner, as proposed in the paper "shade trees" [(C01)]. Besides enabling modifications to the shading of the mesh and creative abstract lightning models like toon shading, it enables at the same time generating procedural surface property information. While the interfaces of real time renderer already make use of the GPU with fragment shaders, offline render applications ,which are ray tracing the scene instead of rasterizing, require also implicit algorithms to evaluate a surface color at arbitrary points by ray intersections. Therefore the functionality and behavior of these interfaces are oriented towards fragment shaders. The interfaces are also shipped with abstract implementations of various useful algorithms to hide the underlying complexity.

Artists like Simon Thommes already pushed the limits of these interfaces really far and they were able to create stunning materials, only using procedural methods without any dependency to external resources like textures.



*> [Figure02] Procedural Materials in Blender, created for "Nodevember"; Made by Simon Thommes 2019*

## 1.1 Motivation

Due to the possibility to use and layer multiple algorithms in shaders and interfaces of various render applications, creating procedural materials can be still a tedious and complex task. Manipulating results of algorithms in the right manner often relies on repetitive tasks and practical knowledge to get convincing results. Because the endless possibilities and creative freedom for manipulations and choice of algorithms in shaders and interfaces of render applications will not enforce or guide creators to a specific workflow to create procedural materials. And additionally, only implicit algorithms for pattern generation can be used, because of the shader architecture. This excludes the use of post processing algorithms like blur, normal map generation from height or ambient occlusion. Post processing algorithms rely on neighbor information which cannot be accessed without buffers in fragment shaders. Buffers are not available in every render application interface and if it does, the usage of them can vary for each render application interface.

## 1.2 Objectives

This thesis will serve multiple objectives. First, an understanding for real world surfaces and their composition should be created. Therefore they have to be analyzed how they can be decomposed in distinct information, layers, forms and patterns. Secondly, to know which algorithms are suited for procedural generation and which common use cases are occurring, a categorization based on their task and type needs to be created. Thirdly, guidelines have to be defined, in order to reduce Trial-And-Error phases and guiding creators to a structural process. Finally the analysis, categorization and the capabilities of the workflow are tested by creating a procedural texture and documenting each step.

The order of the named objectives will also represent the structure of the thesis. Details about implementation or specific algorithms are not part of this work. As well as a performance analysis of algorithms or entire procedural materials.

# 2 Prerequisites

By dealing with render applications, procedural texture generation and shaders, some terms can have similar meaning and sound. Therefore their meaning in this work has to be defined to prevent misunderstandings.

## 2.1 Procedural

The paper "A Survey of Procedural Noise Functions" defined “procedural” as:

"The adjective procedural is used in computer science to distinguish entities that are described by program code rather than by data structures. Procedural techniques are code segments or algorithms that specify some characteristic of a

computer-generated model or effect." [(LLC01)]

## 2.2 Textures

Textures are images where a single or more information about surface properties is stored. Combined with the definition for "procedural", a “procedural texture” is defined by Dr Sebastien Deguy as: "[...] a computer-generated image created using an algorithm [...], instead of a digital painting or image processing application[...]" [(D01)]. Render applications are then using these textures to feed the properties of an assigned lightning model.

## 2.3 Materials

Most render applications using the term "material" for the combination of the used lighting model and the collection of information for the lightning model, like albedo or specularity. This thesis uses the term "material" for the collection of information only, excluding the lighting model. Because the lightning model has only a minor influence on the process of replicating a surface in a procedural manner.



*> [Figure03] Different lighting models, same material information; Right: Physical based (PBR); Left: Non-photorealistic (NPR)*

As seen in the figure, with different lighting models the visual appearance of surfaces can change drastically, even if the offered information about the surface properties are the same. The lightning model can influence the process of procedural materials by requiring special information. Nonetheless this will not change the general approach of how to analyze and replicate surfaces, as well as the underlying techniques and algorithms.

## 2.4 Implicit and explicit algorithms

Implicit algorithms are more suited for procedural materials than explicit ones. The difference between those two is that an implicit algorithm will answer a query about an arbitrary point and returns information exclusively for it. While an explicit algorithm returns the whole result, evaluated for a resolution defined by the renderer and not by the shader itself. [(EMP01)] Due to the architecture of shaders, regardless of weather used by ray tracing or rasterization, the task of shaders is to evaluate arbitrary points of a surface. These points are defined either in rasterization by the current resolution and view, in case of ray tracing are the points determined by the hit location of emitted rays. Implicit algorithms which can return results to these points without dependencies to neighbor point information and resolution are therefore preferred or even necessary.

## 2.5 Pro & contra of procedural patterns within fragment shaders

Related work already has explored and analyzed several advantages and disadvantages of pattern creation in fragment shaders, besides the named problems for the motivation.. While they are not part of this thesis they still have to be pointed out. The book “Texturing and Modeling - A Procedural Approach” [(EMP01)] already made a good listening of these pros & cons which can be represented shortened as:

* The size of a procedural representation is way smaller than saving their result as texture.
* The evaluation can be executed at any resolution.
* Procedural materials can be parameterized to change the appearance and features.

Disadvantages are:

* The development process can be difficult, because of the complexity of algorithms and the lack of debug possibilities.
* Results of chaining algorithms are hard to plan without practical knowledge.
* Evaluating can be slower than accessing textures.
* Aliasing can be a problem, especially for far zoomed out textures.

# 3 Analysis of surfaces

The overall objective of the analysis should not confound with building a physical and chemical understanding of real world materials, which nonetheless may be helpful or necessary. The main objective is to extract patterns and geometric information about the visual appearance. To retrieve these information, the analysis of surfaces is carried out in three steps:

- Extracting surface layers

- Visual properties of materials

- Environmental influences

The steps were derived on one hand by looking through guides of the specialized software for procedural texture creation “Substance Designer” [(SD03)], and on the other hand by transferring the knowledge to a pure shader based environment. While creating several textures, these steps have been evolved over the time by analyzing several types of surfaces with the goal in mind to get the information as structured as possible. To support each step in their explanation, their concept is applied to an example reference photo of a wooden floor in a Pub.

The proposed extraction steps rely on pattern, noise and shape recognition. The retrieved information about the surface composition and visual features is reused later by replicating them with matching algorithms, order and techniques that are available to fragment shaders. To utilize the extracted information, they can either be implemented directly while analyzing the surface in parallel or persisted in any preferred way. The implementation does rely on the content of the information, not on its persistence.

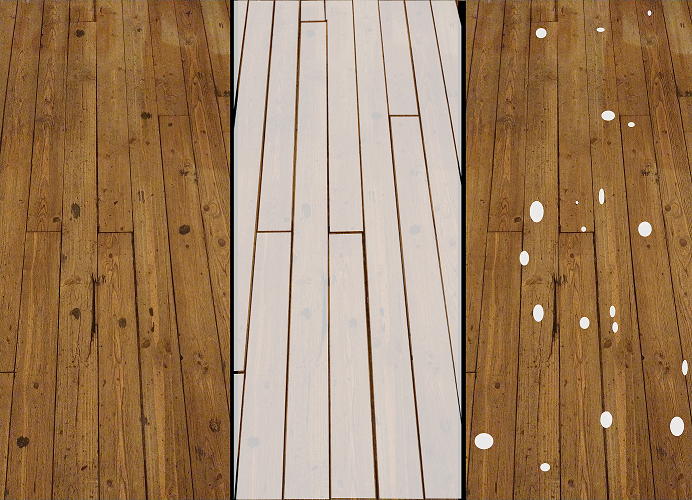
## 3.1 Extracting surface layers

Separating surfaces into different layers of sub-materials helps later to reassemble the surface in the material in the same manner as image editing software does this through blending them into an final image. In addition the separation serves as simplification to the reference surface to overcome possible complex compositions, which then can be understood more easily detached from other influences.

A hierarchical approach for looking out for layers is recommended, because the depth of the analysis will differ by the required level of detail for the material. Further the hierarchical approach can also mimic the creation process, physical and chemical processes over the lifetime. These influences create natural layers of materials on a surface, like leaves on the ground, oxidations or screws in furniture, which almost matches the chronological appearance and history of the surface. Another advantage of a hierarchical approach is the option that replicated materials can be reused in other materials, because the layering should only control their distribution in the final material.

Factors which are decisive for separations are:

* Physical factors; Many surfaces are already separated naturally through manufacturing processes, like stone walls and floors, where the final surface is man made. It also includes occurrences where different materials are placed on top or worn away without initial intent, like posters on a wall, leaves on grass or peeled plaster
* Chemical Factors; surfaces will change their appearance over time. Oxidation is a typical everywhere occurring process for metals, where the metal slowly converts to rust.
* Abstract patterns; Surfaces may also have noticeable features which are expressed in height, color or other properties without dependency to a distinctive material. Patterns on wallpapers or height structures on surfaces to provide more grip are an example of that.



*> [Figure04] Left: Floor of a Pub; Mid: Separation by planks; Right: Separation by trampled gums*

The first separation is made by the wooden planks, because:

* The planks are physically separated and are independent to each other.
* they are the most perceptible feature of the floor.
* they control the base height of the surface.
* the arrangement and shape results in an almost regular pattern.

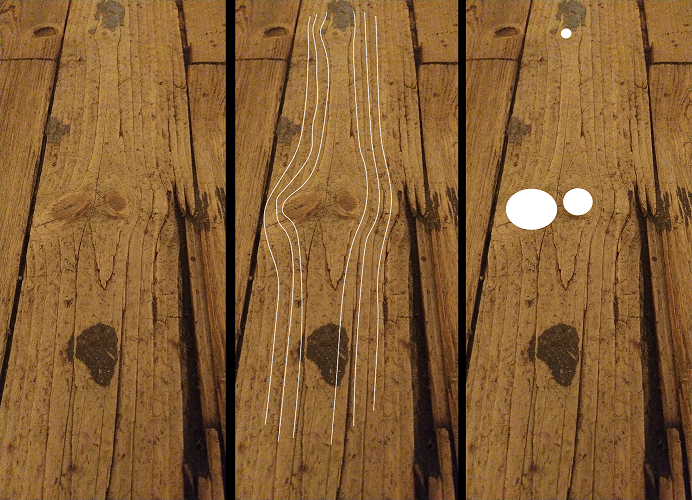
While the first separation is oriented to the wood structure, the black dots on the floor appear to be independent to the plank structure. This is because these dots are old trampled chewing gums. Therefore a second separation is made since:

* they do not show a dependency to the plank or wood structure and overlap some planks.
* they are a different material than wood.
* they are physically placed on top of the floor.

## 3.2 Visual properties of materials

After separating a surface in multiple layers, visual properties about the isolated materials have to be extracted for recreation. Again a hierarchical approach is recommended, this time driven by the obtrusiveness of visual features, which ensures that the material is later immediately recognizable. The hierarchical approach matches the later proposed workflow for implementation by iterating from rough to small details. This takes only features into account which are necessary and required by level of detail for the material.

While the factors for the separation often are quite obvious, the extraction of features from materials is still oriented to the named factors earlier.



*> [Figure05] Left: Single plank of the floor; Mid: Annual rings, Right: Branches*

The floor planks are made of wood. The two most recognizable features of wood are annual rings and branches, which are also represented in the reference photo. There are more features in the reference photo which can be extracted, but the two initial features, annual rings and branches, are enough for a first recognizable implementation of a wood material.

## 3.3 Environmental influences

While a surface can be separated into layers, and the materials which made up the layers are treated separately, a surface is still part as a single instance of the environment. This means the environment where the surface exists has a strong influence on the appearance. Trampled chewing gums on the floor are a result of an environmental influence, because the floor is located in a public place, a wooden floor in a living room may not have the feature of trampled gums.

Visual features which may appear at first glance inexplicable often can be explained by looking though the history of a surface. Environmental influences are the factors which make materials finally believable. Thinking about the environment and gathering background information about the history, conditions or story can leave visual impressions on surfaces. This knowledge can be applied factionary to surfaces to integrate them in the resulting material to fit more convincingly in the final environment.



*> [Figure06] Left: Floor in a Pub; Mid: burned spots from trampled cigarettes; Right: color variation due to spilled liquids*

The wooden floor of the example is no exclusion to that. The floor is located in a smoking area and in the reference photo are all over the place small dark points like "freckles" on the floor. With a close inspection these freckles are identified burned spots from trampled cigarettes. Another information to consider in a pub is the possibility of spilled liquids. These liquids may not be wiped away immediately, so the liquid will be soaked up from the floor, which can cause discolorations to the wood.

# 4 References

# 5 Figures