

Progressive raster imagery beyond a means to overcome limited bandwidth

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ABSTRACT

Progressive refinement is a well-established approach to overcome bandwidth limitations in mobile environments. One outstanding benefit compared to related approaches is the provision of meaningful content previews during data transfer or processing. Although highly relevant and useful, however, related literature only addresses the support of this functionality by certain communication stages or proposes systems for specific use cases. No publication is concerned with an abstraction or formalization of progression or takes advantage of its beneficial properties in other application fields.

In this publication we want to give a general view to progression, its key concepts, attributes, and common data processing pipeline. Thereby, we abstract from specifics and usage scenarios in order to simplify the development of new algorithms and schemes and to derive guidelines for its general application. To show that progression is also able to solve problems beyond limited bandwidth, this contribution is also concerned with the introduction of new application areas. The novel idea of content-oriented refinement allows emphasizing important image regions by an animated tour-through-the-data. It will also be shown that progressive representations are a very effective means for device adaptation. Both applications are motivated, discussed, and illustrated by different examples.

Keywords: Progressive refinement, Image communication, Visualization, Context adaptation, JPEG2000

1. INTRODUCTION

The constantly increasing size and dimension of visual contents are one of the main challenges in mobile computing. The sheer amount of data affects all processing stages from storage to display – there is simply too much data to be suitably handled and presented by traditional technology. This results in long response times and thus in low usability. This problem is not new and many different approaches addressing single or multiple aspects of the associated issues have been proposed.^{1,2} Progressive image transmission and refinement is one of the established approaches.^{3,4} By providing the viewer with continuous previews, a highly responsive image viewing and browsing experience can be achieved. Related literature, however, either focusses on single components of an image communication system (e.g. compression or transmission) or specific application scenarios. No publication is concerned with an abstraction or formalization of the approach to derive common statements advancing its understanding and future use.

In this publication we want to give a general view to progressive image handling (*Progression*), its key concepts, attributes, and the processing stages required to generate progressive presentations (cf. Figure 1). Thereby, we abstract from any specifics in order to be able to derive guidelines for their general application and to simplify the development of new algorithms, compression schemes, and usage scenarios. Although, in recent years there has been little interest in progressive refinement, it is our opinion that existing applications do not reflect the whole potential of the approach. Thus, the majority of this publication is concerned with the introduction of new application areas for the approach. Progression supports many accepted visualization principles and thus is able to enhance the *image presentation* by a pre-defined or interactive tour-through-the-data.⁵ In order to avoid long response times and to decrease resource consumption, the scalable manner of progression may also be used for *device adaptation*.

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This publication is structured as follows: Section 2 serves to review the State of Art in progressive data handling. Based on this, Section 3 is concerned with its general concepts and fundamentals properties. Later on, two new applications – progressive image presentation (Section 4) and device adaptation (Section 5) are introduced. The eligibility of progression applied to imagery is discussed in Section 6. Conclusions and directions for future work close this contribution in Section 7.

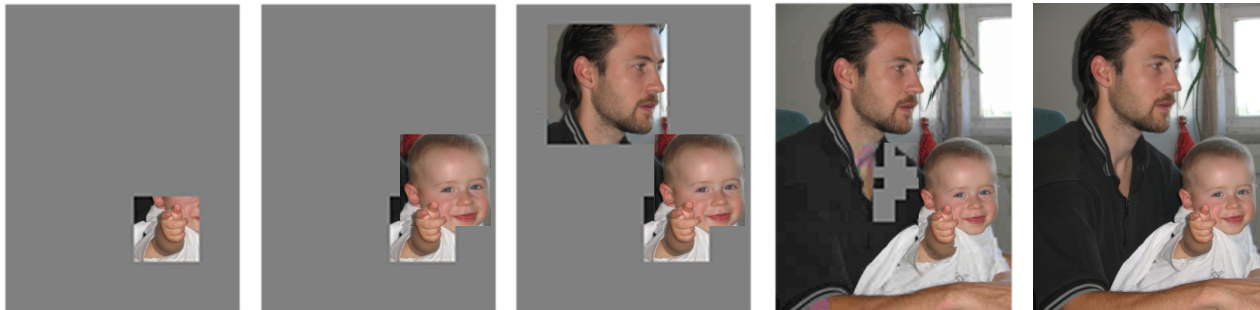


Figure 1. Application of progressive refinement to provide a tour-through-the-data.

2. PROGRESSIVE REFINEMENT IN LITERATURE

By talking about progressive refinement the reader might be instantly reminded on the early days of the World Wide Web, when limited bandwidth was a big issue.⁶ To shorten the long latency times during the loading of imagery, the proposal of dynamically refining contents was a real relief – with little data received, first conclusions could already be drawn (cf. to Figure 1). Due to its success, the approach has later also been applied to other kind of data (e.g. volume,⁷ geometrical,⁸ or abstract data⁵) in order to overcome resource limitations in computational power⁹ or memory.¹⁰

Image and video communication have always been the main application fields for progression.^{3,4} First systems have already been proposed in the late 70s.³ In 1984, LOHSCHELLER⁶ proposed the first progressive image communication scheme. After the focus of the research community shifted to achieve higher compression ratios by proposing *lossy* compression schemes, leading to the development of the *JPEG-standard*¹¹ and *wavelet-based approaches*,¹² the advent of the WWW drew back attention to progressive compression schemes. Due to their provided features especially wavelet-based approaches have been of main interest. They opened the horizon for *scalable image compression*. The basic idea of this approach is to organize the encoded data-stream in such a way that the decoding of a truncated stream leads to a restored image with less detail.¹³ Thus, content previews can be presented during a still running transmission. Thereby its is common sense to place the most important information at the beginning of the stream followed by less important refinement data. Thus, all encodings of an image at low bit-rates are an integral part of the data-stream created for a higher bit-rate. To combine the requirements of this procedure with a high compression performance sophisticated codecs such as SPIHT¹² or JPEG2000¹⁴ have been developed.

Beside the uniform refinement of the whole image, further developments allow to decode and view important image regions earlier than others.^{15,16} This concept is called *Region of Interest (RoI)* and will be discussed in more detail in Section 3. Similar to the general approach, data contributing to the reconstruction of an important region is placed first in the stream, which leads to *interest ordered* data. Any valid stream termination leads to an image where important regions are presented exclusively or at a higher quality than others. Dependent on the option to interactively change an RoI during streaming, there are two main kinds – static^{14,17} and dynamic RoIs.^{18,19} Due to their ability to adapt to changing demands and the implemented paradigm - *Compress Once: Decompress Many Ways*²⁰ - dynamic RoIs are of exceptional importance in interactive environments. However, strategies to encode static or dynamic RoIs often apply same principles.

Due to strong heterogeneity in the currently available device range, the capacity to handle certain work items varies strongly and may be less than required for a certain task. The needed adaptation of the presented contents is an important problem not only existent in image communication. A research field especially dedicated to solve the associated issues is *Multiple User-Interfaces* (MUI).²¹ Interestingly, its aim to achieve access to centrally managed information and the resource-driven display have strong analogy to common imaging technology²² and the progression approach. As MUI comprise many benefits for any application field requiring visual output in heterogenous environments, first works strive to apply this approach to different kinds of data and tasks.²³ This, however, is still a rather novel research topic. Specific proposals for device adaptation of digital imagery are usually not suited for interactive environments characterized by frequently changing demands.²⁴ Although there are approaches taking advantage of progressive refinement,²⁵ they are usually founded on an interactive abortion of data handling and transmission to avoid resource exceeding.

In addition to imagery, progression has also been applied to other kinds of data. EVERITT AND YEE⁹ use the approach to visualize the result of massive data queries. Each of the previews shows a combination of already retrieved data with abstractions of items still to come. This allows for conveying information about the data even in early stages of such complex tasks and saves resources by the option to finish the refinement process at any time. Beside such technical concerns, progression is also able to increase the expressivity of content presentations. It has been shown⁵ that by creating well-defined successive previews, it is also possible to inherently highlight certain data characteristics and to significantly simplify device adaptation. In spite of these advantages, it is remarkable that progressive technology has only sparsely been applied in these application fields.

Summarizing related publications, numerous approaches take advantage for progressive refinement and underline its eligibility for different application domains. Of exceptional importance especially for mobile environments is the thereby achieved reduction in resource consumption, mostly computing power and bandwidth. Existing proposal for abstract data also suggest the appropriateness of the approach for enhanced content presentation and device adaptation. However, there is no related literature abstracting from specific problems and providing generally valid statements to the fundamentals, requirements, and general procedure of the approach. This would be of great value for its understanding as well as the development of future technology and suitable applications.

3. THE FUNDAMENTALS OF PROGRESSION

Successive refinement of raster imagery is one of the commonly known applications of progression and found in many implementations for resource-limited hardware. There is simply a strong need for technology able to deal with the constantly growing increase in detail. Common to all proposed strategies is that there are multiple successive previews each adding incremental detail to the displayed contents. How this can be achieved and described will be shown in this section.

3.1. Regions of Interest and Levels of Detail for raster imagery

Idea and fundamentals of progression may be described by the concept of Regions of Interest (RoI) and Levels of Detail (LoD). RoIs allow for a distinct description, handling, and prioritization of different image regions and can be achieved by an appropriate partition of the image. In case all regions are to be equally treated, a single RoI covering the whole image is used. To determine the specific interest for a particular RoI, in literature often simple schemes founded on quality by predetermined²⁶ or adapted values,²⁷ or specific image content²⁸ have been proposed. Such schemes, however, are not sufficient for a generic specification of the interest.

To achieve a reasonable specification, LoDs may be applied. LoDs have their origin in 3D-image rendering,²⁹ where they have been successfully applied to render objects far from the viewer with less detail. Although also used by FURNAS³⁰ in a similar manner, the idea has first been ported by RAUSCHENBACH AND SCHUMANN³¹ to describe flexible image transmission.

An LoD is basically a 4-tuple consisting of the attributes *x-resolution* ($0 \leq x\text{-resolution} \leq 1$), *y-resolution*, ($0 \leq y\text{-resolution} \leq 1$), numerical *accuracy* ($0 \leq accuracy \leq img_a$), and *component* ($0 \leq component \leq img_c$) located in a 4-dimensional euclidian *LoD-space*. An arbitrary combination of the four attributes indicates the particular interest to the corresponding region. The origin of the LoD-space refers to a RoI for which no belonging

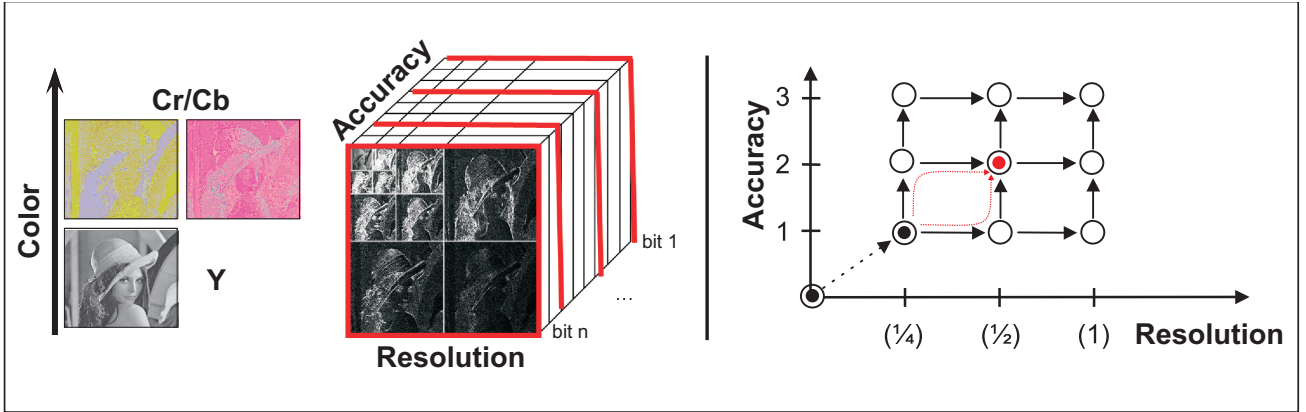


Figure 2. Scalable coding of raster imagery as a fundamental property of a progressive representation (left), and a model for the description of the progressive refinement by Levels of Detail (LoD) (right). Based on an underlying LoD hierarchy, multiple LoDs (circles) and refinement paths (arrows) are provided. To achieve a certain LoD different paths may be possible (red arrows and dot).

data is considered ($LoD(0, 0, 0, 0)$). An LoD of $LoD(1, 1, img_a, img_c)$ indicates that all available data is required to represent the RoI.

Based on this definitions, it is possible to describe progressive image handling even in interactive environments. To specify how to achieve a certain detail level, an LoD is subdivided into a *target-LoD* determining the current interest and a *state-LoD* representing the already available degree of detail. To avoid redundancies while switching from state- to target-LoD, *hierarchical LoDs* with their inherent scalability are of great importance (cf. Figure 2/left). They are founded on the idea that starting from a certain hierarchy level, only incremental data, the *LoD-delta*, is needed to achieve higher LoDs (cf. Figure 2/right). This principle leads to the strived *progressive refinement* of the content. A new target-LoD residing at a lower hierarchy level than the current state-LoD can easily be extracted from the available data.

As progressive refinement only describes the ability to achieve a certain target-LoD based on a given state-LoD, it does not provide statements for its deterministic implementation. This depends strongly on the supported LoD combinations and refinement paths of the provided LoD hierarchy (cf. Figure 2/right). If there are different paths to achieve a certain LoD, it is meaningful to prioritize the LoD-axes. This ensures that the different refinement steps are always determined by a unique path through the hierarchy. How to achieve a suitable hierarchy and its appropriate traversal are discussed within the next section.

3.2. Progressive image handling and transmission

Progression approaches proposed in literature are often very specific and described as indivisible part of compression or transmission schemes. In order to outline the different involved processes and to be able to appropriately describe existing and future applications of this approach, this section proposes a generic processing pipeline for progressive image handling and transfer. We carefully analyzed existing technology and abstracted the applied ideas in order to make the general procedure more graspable. Thereby, we focus in our statements on the most demanding interactive client/server setup to be able to consider the State of Art in image communication and the request for systems able to react to frequently changing user demands. The main goal is resource-efficiency at client and server side.

A single image out of a pool of *imagery* is passed to the system as *2D-pixel array*. *Encoding* and permanent *Storage* of the *Progressive data structure* appear on *Server-side* to consume most of the required computing power at the stationary system part. *Traversal* accesses the data structure whenever content is to be served and generates the previews dependent on the *Author* or current *User preferences*. The *Client* only consists of a *Decoding* unit adapting the received data to the requirements of the respective *Viewing device* and displaying the previews successively. This processing pipeline is illustrated in Figure 3. The following listing provides more detail to each individual component:

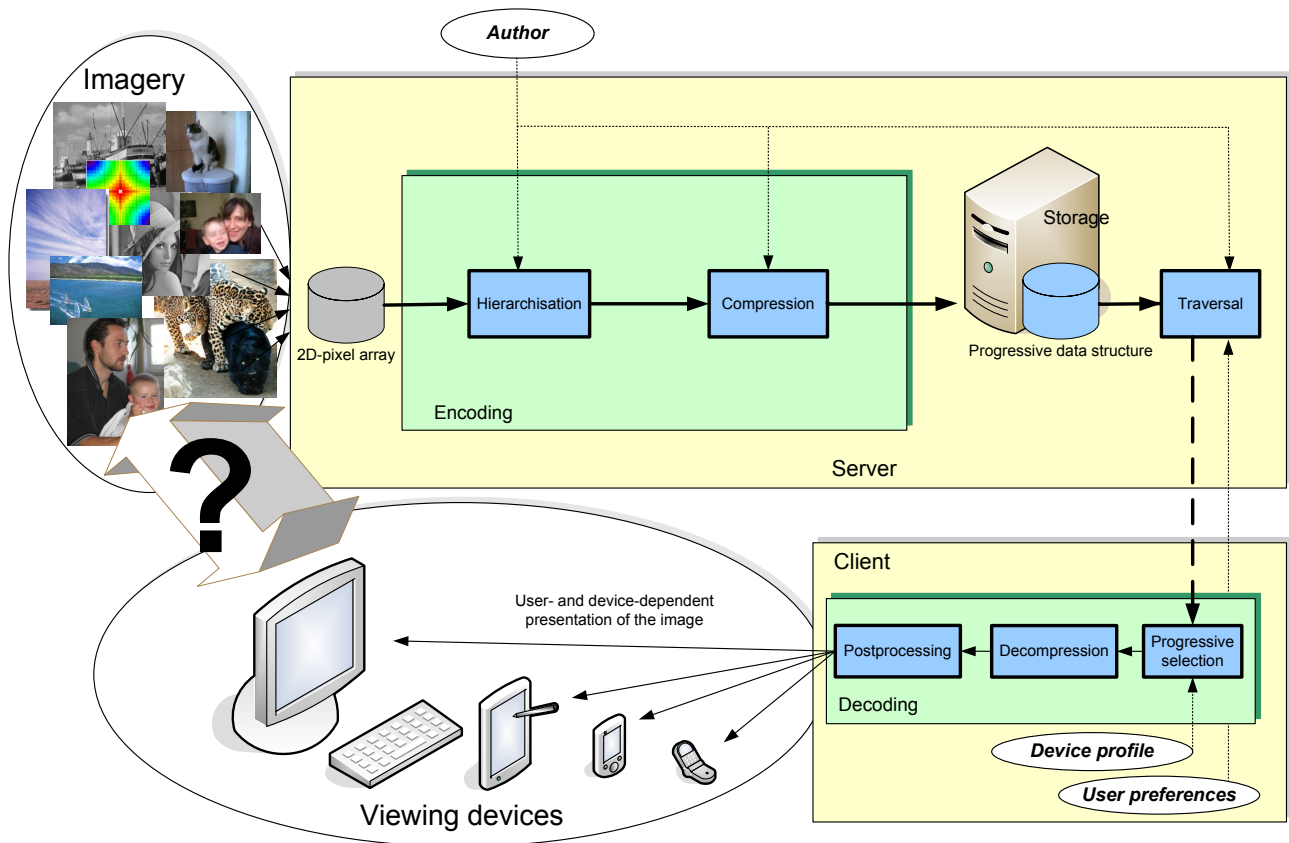


Figure 3. A typical processing pipeline for progressive image handling and transmission allowing for an enhanced image presentation and adaptation to heterogenous viewing devices.

Encoding: This tier creates the *Progressive data structure* basically consisting of a compressed LoD hierarchy of the contents. This is achieved by *Hierarchisation* of the pixel data and a following *Compression* of the resulting structure. Due to the multiple options for each of these processes, the *author* has full control to select the most appropriate solution.

Hierarchisation of the pixel data is required to create the LoD hierarchy needed for progression. Thereby, a number of requirements must be satisfied: (1) *high scalability* of the content for many supported LoDs, (2) *random access* to image regions to support RoIs, and (3) a *high decorrelation* of the data for better encoding efficiency. A typical example to achieve these aims for raster imagery is the well-known Discrete Wavelet Transform (DWT).³²

Compression increases *encoding efficiency* by a reduction of the data volume. As hierarchical structures often contain redundancies, this heavily decreases resource consumption of the whole system. However, compression is required not to significantly limit the access to the different LoDs of the hierarchy in order to take advantage of them in later processing stages. Typical compression schemes supporting the introduced requirements for hierarchisation and providing high compression efficiency are SPIHT and JPEG2000.

One-time storage: The *Progressive data structure* is encoded once, permanently stored, and used multiple times to serve requests of different clients. This implements the paradigm – *Encode once, decode many ways*²⁰ – significantly reducing the consumed system resources within the whole system.

Traversal: The LoD hierarchy represented by the *Progressive data structure* may be traversed in different orders. Thus, for every client request and current requirements a suitable order may be chosen. In turn,

this strongly influences the transmitted data and thus the provided previews. Although, a general order might already be defined by the *Author*, the process can be dynamically adapted to changing *User preferences*. As later display of high detail for all contents is often not required or possible, the length of the traversal path may also be chosen depend on the capabilities of the *Viewing device*.

Decoding: This tier manages the progressive display of the image on the respective viewing device. *Progressive selection* successively extracts the still encoded individual previews from the received data. By making use of a *Device profile*, it is thereby checked whether the next preview can be displayed or not. In the first case, the belonging data is requested from the server and passed to the *Decompression* component. A downstreamed *Postprocessing* unit renders the preview and displays the result.

The proposed pipeline illustrates the procedure of the progression approach schematically. To increase performance in practical implementations, components might also be combined to allow for faster integrated processing.

3.3. Key attributes of progression

As shown in the previous section, the progression approach needs certain processing stages and requirements in order to allow a communication system to take advantage of its beneficial properties. This section is dedicated to summarize these characteristics in order to outline its key attributes.

Scalability During progressive refinement abstractions of the image are shown in multiple subsequent previews with increasing LoD. This requires scalable access to the image data. Thus, progressive data structures are inherently scalable. The most appropriate approach to introduce scaling in raster imagery is transformation.

Random access Often not all image contents are of same importance. To allow for prioritization between image regions, belonging data within the LoD hierarchy must be independently accessed, attributed, and assigned to the different previews. Random access is also crucial for a dynamic and resource-efficient adaptation to interactive changes.

Compression Huge imagery requires efficient compression to avoid problems in transmission and storage. This especially applies for hierarchical representations. Suitable compression schemes take advantage of the hierarchical data structure and add only increments to achieve higher LoDs.

User preferences The progression approach has been developed to increase response rates and thus usability in resource limited environments. While first systems were constrained by pre-defined and fixed progression orders, new developments allow for dynamic adaptation to user preferences during streaming or processing. The preferences itself can be described by the RoIs and LoDs.

It is worth noting that the appropriate implementations of some of the stated attributes, e.g. random access and compression, are contrary leading to the problem that not all demands can be fully implemented. This may be solved by developing solutions that consider the specifics of the respective environment and which provide reasonable trade-offs in their implementation.

4. PROGRESSIVE IMAGE PRESENTATION

Usually not all parts of an image are of same importance to the viewer. To simplify and fasten the conveyance of the contents it is therefore desirable to prioritize regions visually. Such an importance-driven representation has yet not sufficiently covered in literature and is usually limited to spatial transformation or color coding. Contrary to the use of such "external" mechanisms that alter the original contents, it has been shown that highlighting might also be achieved by taking advantage of properties of the respective image codec.³³

This section introduces a novel approach to achieve an importance-driven image representation by taking advantage of progression. In order to enhance conveyance, defined image regions are emphasized and shown earlier than others. Due to the properties of progression, the proposed approach can be tightly integrated into image handling and transmission and does not require additional resources. The following paragraphs discuss its semantical as well as technical aspects.

4.1. Semantical aspects

Progression is able to provide a successive presentation sequence. Thus, instead of viewing the image at once, its contents may be presented by multiple views similar to an animation. Thereby, first previews refine important, later previews less interesting parts of the image. As each preview adds detail to the presentation, this allows besides a temporal prioritization of important regions for an incremental buildup of knowledge about the contents. The thereby applied paradigm –*progression instead of selection*– allows for the extension of the traditional interactive image exploration by a progressive presentation in terms of a *tour-through-the-data*. As the refinement itself leads to visible changes, the attention of the user is intuitively drawn to the modified areas. Thereby, uninteresting regions are often blurred providing additional viewer guidance.³³

The refinement sequence can be individually designed and thus can be aligned to achieve a certain presentation goal. Goal and sequence are usually pre-defined by the author (cf. Section 3.2). In case of different or changing interests at viewer side, however, the sequence can also be interactively adapted to other needs.

Such a *progressive image presentation* supports well-accepted principles of data visualization. Due to long response times and limited screen space, large amounts of data can often not completely processed and presented. To overcome these problems, the *Information seeking mantra*³⁴ – *Overview first, zoom and filter, then details-on-demand* – is one of the mostly applied and well-accepted paradigms if data is to be visualized. The progression approach is quite similar to the mantra. It provides an initial overview of the image which is later on successively increased in detail. Due to the availability of previews, first insight is gained much in advance to the full representation. Although this seems similar to traditional animation, the different views are tightly bound and not independent. This is an important difference to most related approaches. However, many of the properties found in successful animations are well supported.³⁵

Progressive image representations allow for an enhance content conveyance paired with high flexibility and may be implemented by the communication system shown in Figure 3. To achieve this, the author is required to pick a valid hierarchisation approach and adapts the traversal of the resulting structure depending on the aspects to be conveyed. In case of interactive changes, this traversal is modified to adapt the following previews to the new demands.

Different strategies for the design of an appropriate presentation sequence are imaginable. They strongly depend on the respective presentation goal. Common to all, however, is the general approach to show important data first and to postpone the remaining data for later display. This data might also be skipped to save resources. The following list shows the 2 basic strategies serving as a foundation for more sophisticated presentations.

Exclusive RoIs The probably most obvious application of progressive image presentation is the exclusive refinement of important image regions. The presentation of the background is postponed till these regions are shown in full or high detail. If there are multiple regions of importance, they might be further prioritized.

Figure 1 illustrates the different options by an example. Preview 1-3 show the prioritized refinement of 3 different RoIs. After they are available in full detail (Preview 3), the background is refined in order to provide context (Preview 4). This illustrates that the progression approach is able to highlight different pre- or interactively defined image regions within a single refinement sequence. The final representation is identic to the original representation (Preview 5). Another application demonstrating the exclusive refinement of an RoI is shown in Figure 4/left.

RoIs and context Instead of an exclusive RoI refinement, the simultaneous refinement of RoIs with different assigned LoDs provides further benefits for progressive presentations.

Figures 4/middle and right show typical previews created by applying this strategy. The progressive refinement of a most important focus regions is combined with the refinement of surrounding areas in low detail. This allows for providing additional context to the focus even before it is shown in full detail. Additionally, the resulting representation imitates the Depth-of-Field effect of the human visual system. This has been proven to intuitively guide the attention of the viewer to the focus.³³

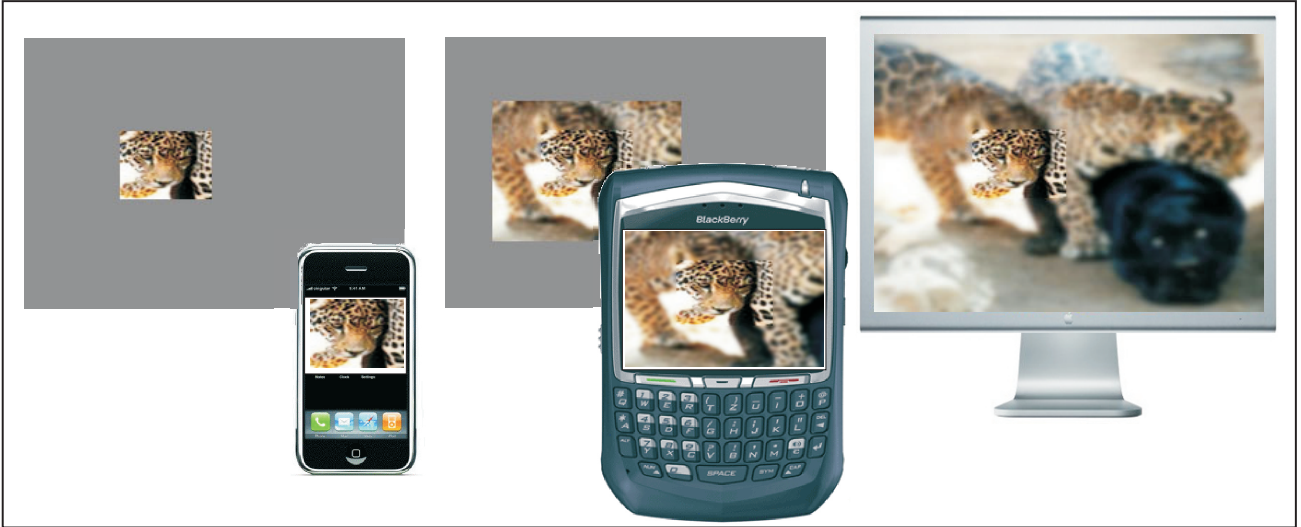


Figure 4. Adaptation of an image to different viewing devices using a single progressive presentation.

4.2. Technical aspects

Beside the support of a novel kind of image display, the progression approach is also able to significantly save consumed bandwidth and computing power. This is possible due to the following two properties of appropriate progressive presentations:

1. First previews require little data, as the volume of data becomes significant only in the later, more detailed previews.
2. Important contents are shown in advance to less interesting data.

The save of resources may be easily implemented by a truncated data traversal at server side (cf. Section 3.2) either determined by author or viewer. This directly reduces bandwidth consumption and the amount of data to be decoded at client side. The following statements explain implementation and savings for each of the introduced presentation strategies. Thereby, an identical saving of bandwidth and computing power is assumed for simplification. As the presentation is created once and frequently reused, server load is negligible.

Exclusive RoIs The support of an exclusive refinement of distinct image regions is mostly achieved by the provided options for Remote Spatial Access. Thus, data contributing to the reconstruction of the respective region can be separated, and only this data must be transferred and processed to display the according region. Data belonging to the background is often skipped.

The resource savings correlate directly with the ratio between the available image and screen dimensions f , $f = \frac{RoI_{width} \times RoI_{height}}{Img_{width} \times Img_{height}}$, and can be approximately stated as $(1 - f) \times 100\%$. Thus, as bigger the image and as smaller the RoIs, as higher the saved resources. Compared to the original volume, approximately 5%, 10%, and 25% of the data is required to provide the previews 1-3 shown in Figure 1.

RoIs&Context This strategy displays image regions at different LoDs and thus requires distinct considerations for each kind of region. The RoI representing the focus is displayed in full detail. Thus, all data available for this region must be transmitted, which corresponds to the statements provided for exclusive RoIs. The context, however, is displayed at low resolution. To give an approximation of the resource savings, the reasonable assumption that starting from the lowest resolution provided by the LoD hierarchy the required data increases exponentially with the support of each higher resolution. By assuming the number of all resolutions to be nmb , the data needed to reconstruct an image downscaled by factor s , with $s = \frac{1}{xres}$, $xres = yres$, $xres, yres > 0$, can be stated as $2^{2(nmb - \lceil \log_2 s \rceil - 1)}$. Thus, the save of bandwidth and complexity is $(1 - \frac{2^{2(nmb - \lceil \log_2 s \rceil - 1)}}{2^{2(nmb - 1)}}) \times 100\%$,

which is already 75% for an image with spatial dimensions reduced by factor $s = 2$. Although, part of this data is also used for the reconstruction of the focus, its amount is negligible.

As it has been shown that visual image representations can be described by RoIs and LoDs,³⁶ these statements may be combined to calculate the respective savings of other more sophisticated presentations. In case of interactive changes, a non-redundant data transmission can be ensured by taking advantage of the property that the underlying LoD hierarchy allows for incremental refinement. Based on the refinement path, only a delta instead of new data values must be provided to achieve a higher LoD.

These statements show, that progression is able to enhance the conveyance of image contents and to reduce consumed system resources simultaneously. Another, application field of progression which may be combined with these benefits is introduced in the next section.

5. DEVICE ADAPTATION

Properties and resources of currently available viewing devices are manifold. Thus, the viewer of large imagery has often no clues if the data to be displayed exceeds the computing power, bandwidth, or screen space of the device at hand. If so, the user is confronted with long response rates and thus heavily delayed interaction feedback. To overcome this, image handling and displayed contents must be adapted to the capabilities of the respective device (cf. Figure 4). Although, there are different approaches to achieve this, they are usually too costly in terms of resources, which makes them not appropriate for resource-limited hardware. There is still no general solution to this problem.

An uncomplex adaptation to the capabilities of the viewing device can be achieved by taking advantage of the inherent scalability and modular structure of progressive presentations. This avoids the negative effects imposed by huge imagery – the content is refined as long as the device is able to provide the required resources. Thereby, the used overview-then-detail principle nicely corresponds to the increasing resource consumption during presentation – first previews require little, later previews much resources. We propose two strategies to achieve this, each with different properties and suitable application fields:

Profile-based adaptation This kind of adaptation is based on prior knowledge to the image, the used displaying technique, and the viewing hardware to generate a visual representation that fits to the properties of the device. This is mainly achieved on the basis of profiles. These profiles describe relevant properties of the respective component and have been designed to allow for matching in order to identify the best possible fit. The result are those data pieces and contents that do not exceed the available computing power, bandwidth, and screen space. While this approach is often complex, it can be significantly simplified by using progression and its inherent scalability property. The best match basically determines a cut of the underlying LoD hierarchy separating currently valid and invalid image parts. The whole adaptation process takes place at server side. Only valid parts are transferred and displayed at client side.

On-the-fly adaptation Profile-based adaptation is founded on prior knowledge and thus requires additional efforts for the meaningful integration of new imagery or devices. Our proposal for an on-the-fly adaptation requires only a progressive presentation and is applicable to any viewing device. The strategy is simple and effective – the different previews are piece-wise presented as long as the device is able to provide the required resources. If it is estimated that the consumption of one resource exceeds the capabilities of the device, e.g. by measuring response rates or transmission costs, the presentation stops. Although for devices with strong limitations the presentation sequence might be short, the provided previews still allow for the display of meaningful information (cf. to Figure 4/left). The adaptation process takes place at client side, but also requires mechanisms to stop data transmission of the server.

By using transformed imagery with high scalability and well-defined traversal, both strategies lead to a highly adapted content display whereby only essential parts of one single *"multi-purpose" data structure* determined by the respective traversal path and depth are processed and transmitted. This underlines the appropriateness of the progression approach for device adaptation. One possible application field strongly benefitting from the proposed adaptation scheme are *smart environments*. These environments are decentrally organized and consist

of different cooperative devices with strongly varying properties. Thus, device adaptation of displayed contents is mandatory and rather challenging. The proposed strategies are valid solutions to achieve this task in an uncomplex resource-saving manner (cf. to Figure 4).

6. ADVANTAGES AND LIMITATIONS

This section is dedicated to discuss the properties of the progression approach in image communication. We summarize its previously stated *advantages* and complete them by statements to its *limitations*.

Advantages Progression may be used as a new kind of presentation and offers many technical and semantical benefits. By providing well-designed incremental image previews, an efficient and appropriate presentation of the contents can be accomplished. Thereby, the progression approach supports and fulfills many of the principles and requirements stated in literature for successful data visualization. There are many options for a flexible creation and manipulation of the presentation sequence in order to convey aspects of the image as determined by author or viewer.

Another benefit of progressive refinement is its general resource-saving manner. By applying the approach to huge raster imagery, it has been shown³² that the resource consumption does not need to depend on the original amount of data but only on the capabilities of the viewing device. Thus, for small size devices only a fraction of all available data must be transmitted and processed to provide a content representation which is identic to the traditional representation (cf. to Figure 4/left). Thereby, the inherent scalability property allows for a flexible and uncomplex implementation. This is of crucial value for all environments consisting of multiple devices with different properties and capabilities.

Limitations There is no approach without shortcomings. The following paragraphs show the drawbacks of progressive refinement with respect to the consequences resulting from unrealized requirements. It can be generally stated that if multiple attributes can not be implemented, progressive refinement loses most of its benefits.

Scalability The application of progression is meaningless if the image is only available in an encoded representation which is not hierarchical. Although the approach can still be applied, its application and eligibility is strongly limited.

In such cases it is often the better option to reconstruct the pixel representation of the image and to encode the image using the proposed processing pipeline. This also applies if the provided LoD hierarchy is not sufficient to achieve a certain task.

Random access A flexible user- and device-orientated presentation of an image requires its division in independent parts. Similar to scalability this might not always be possible for already encoded imagery. In consequence, the different previews can not be created as required. Representations with insufficient random access should be recoded.

Compression Scalability often adds supplements to the original data and thus increases the data volume. This is not acceptable for massive imagery or systems strongly limited in resources. Thus, sophisticated compression schemes are required. The underlying hierarchical LoD-structure, however, is a great starting point for efficient compression.

User preferences Its currently unclear, if all user preferences regarding image handling and presentation can be supported by progression. This applies especially for all presentation tasks not requiring, avoiding, or inverting the overview-then-detail principle.

There are further drawbacks of the described strategy with regard to device adaptation. Although, the proposed strategies still deliver better results than existing technology, they require additional computing power. This might especially be an issue for client-based on-the-fly adaptation. Furthermore, many other factors influencing a suitable presentation, e.g. the used representation or browsing technique, are not sufficiently considered. This, however, is not a limitation of progression itself, but the proposed adaptation strategy.

7. CONCLUSIONS AND DIRECTIONS FOR FUTURE WORK

Summarizing this contribution, progressive refinement is much more than a means to overcome limited system resources. Inherent scalability and multiple sequential image views also allow for completely novel application fields. *Animated content presentations* provide pre-defined or interactive tours-through-the-data designed to convey relevant aspects of the image. Thereby, the widely-accepted overview-then-detail principle is supported and only a single view is required. The availability of an LoD hierarchy also allows for uncomplex *device adaptation* leading to short response rates and increased usability. Overall, it can be stated that progressive presentations are scalable to both the users interests as well as the properties of the viewing device.

Our future work will focus on two main areas: (1) the enhancement of the proposals for progressive imagery and (2) the application of the approach to other kinds of data. With regard to imagery, especially the proposals for device adaptation require more efforts for sophisticated profile specification and matching. Here, the model-based approaches for Multiple User-Interfaces are good foundations to start with. Due to the fact, imagery is just one of many kinds of data, it is also promising to proof if the beneficial properties of progression and the proposed novel application fields are useful to be applied to other data types. Feedback we received from first works^{5,37} indicates that there is high potential of progressive refinement far beyond its currently addressed application context.

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