



Hi, I am Ondra, and I am the creator of the Corona Renderer. My part of this course is about what changed in the archviz industry in the last 4 years.

WHAT IS CORONA?

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- Modern realistic renderer focusing on archviz



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Just for a quick intro, Corona is a modern realistic renderer focused on architecture visualization. It allows users to create beautiful images such as these.

TOUGH BEGINNINGS

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- Started 9 years ago – school project – one man show

First office:



Celebrating v1 release:



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I started developing Corona about 9 years ago as a one-man show school project. The beginnings were tough. Just to illustrate, here is photo of our first office, and of our celebratin diner when we released version 1.0.

OUR LAST 4 YEARS

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- Commercial release of Corona, founded company
- Big clients, big projects
- Joined forces with Chaos Group/V-Ray



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We were eventually able to pull through, started a company, and released Corona commercially. In the last 4 years we got some big clients and saw Corona used in some high-profile projects - shown here is the Rolls Royce Vision Next Hundred. Finally, about a year ago, we joined forces with Chaos Group.

CORONA TODAY

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- Together with V-Ray: most popular archviz renderers
- 15 developers



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Today, Corona and V-Ray are the most popular renderers in the archviz market, and we have about 15 developers working on it.

CORONA 2014 TALK

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- Mission accomplished ;)
- Ease of use: huge focus
- What else changed since?
 - What we changed?



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I actually had a talk here at SIGGRAPH in 2014, where I claimed that the success we had back then is due to its ease of use. This proved to be true, and now practically everyone recognizes this and focuses on usability the same way Corona did. So because this is now obvious, I would like to talk about some other, more complex changes in the architecture visualization field that we observed, or even caused.



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IRRADIANCE CACHING → DENOISING

“Or how we learned what makes an algorithm the user favorite”

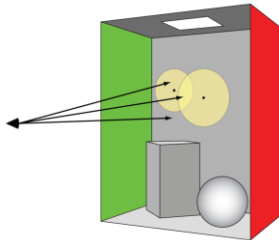
The first and most obvious change is that we changed the rendering algorithm. Specifically, we replaced irradiance caching with denoising. I want to start with this because it nicely illustrates what qualities users like about rendering algorithms.

BEGINNING: IRRADIANCE CACHING

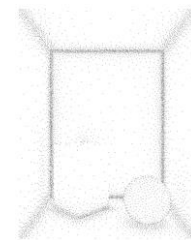
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- Once golden standard
- Stores lighting in scene records, reuses for nearby points

Interpolating records:



Records placement:



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The story begins with Corona implementing the irradiance caching algorithm sometimes in 2010. It was the golden standard of archviz rendering at the time, and everyone had it.

Irradiance caching accelerates path tracing by storing the computation results in few scene points and reusing it for nearby points as you can on left. This means the lighting has to be computed only in sparse set of points as shown on right.

REMOVING IRRADIANCE CACHING

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- Causes many problems, cumbersome
- Removed from Corona
 - Other renderers followed



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The speedup can be massive, but the reuse is also causing many problems like the artifacts shown here. I was never able to solve these problems while keeping the algorithm fast, and in the end, I just removed the whole caching algorithm. Other renderers soon followed us, and irradiance caching quickly disappeared from the market.

NOW: DENOISING

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- Blurring to remove noise (post processing)
- Inhouse denoiser, Nvidia AI Denoiser
- Universal praise from users



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Then, actually unrelated to this, denoising algorithms started popping up. They accelerate rendering by selectively blurring the image in post processing to get rid of the noise. We have both our own high-quality denoiser and also use Nvidia's fast AI denoiser. Both are now widely used and praised by our customers.

ALGORITHMS RECAP

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Biased → **Unbiased** → **Biased**

Irradiance caching
Bad

Denoising
Good?!

- Why?
- Bias does not matter, but other factors do



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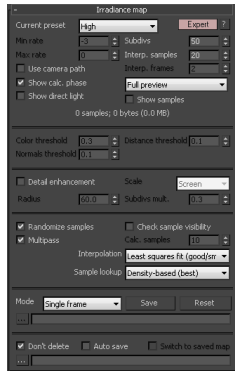
When you think about it, we started with algorithm that blurs the global illumination and removes noise at cost of bias, then we switched to unbiased approach, and then switched back to image blurring noise removal.

This begs the question: what caused the users to reject irradiance caching and praise denoising? It turns out, bias is not important here. Users do not care about bias, at least the way it is defined in research community. We learned that there are other, more important criteria

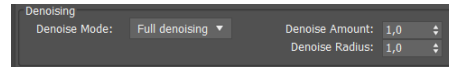
EASY SETUP

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Irradiance caching UI



Denoising UI



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First irradiance caching is notoriously hard to set up properly. Here is example of real UI from production renderer. In it users had to balance many sensitivity parameters, and if they got it wrong, it would produce ugly artifacts. Denoising on the other hand has almost no parameters, as shown on right . This is all we have in Corona, and you can see that it is incredibly easy to set up.

SCALABILITY: COMPLEX SCENES

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- Denoising: mostly influenced by image resolution
- Irradiance caching: penalties for complex geometry, glossy surfaces, ...



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Next is scalability or robustness. Users sometimes have to create extremely large and geometrically complex scenes, like forests, entire airports, or city blocks, and they need to render them with reasonable speed. This is easier for the denoiser, because it just operates on the rendered 2D image, so its runtime is mostly influenced just by the image resolution. Irradiance caching on the other hand had to cover every geometry detail with records, otherwise there would be artifacts, so these scenes came with massive speed penalty.

FLEXIBILITY: ADJUSTABLE STRENGTH

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- Irradiance caching: 100% smooth, smudgy look
- Denoising: nonbinary, can be applied with different strengths:



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Another important aspect is flexibility and control over result. Irradiance caching made the image always completely noise-less. This creates smudgy and artificial look that every artist wants to avoid. In our denoiser, we added a simple slider that blends the denoised and original image together and it turned out to be the killer feature. Almost nobody wants to apply 100% denoising. People just move the slider to get the best balance between noise and smudginess as shown here.

INTERACTIVE/PROGRESSIVE WORKFLOW

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- Denoising
 - + No precomputation
 - + Strength determined after rendering
 - + Quality determined by render time, not before rendering
- Irradiance caching
 - Everything set up upfront
 - No way to remove, fix bad settings after render



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Which brings me to the last point, interactive and progressive workflows. Denoising has no precomputation phase, so it can be used with realtime and interactive rendering. Users can first render regular image and only then choose if it is necessary to denoise it. And if they try it and it fails, they can actually continue rendering for a while longer and then try again. With irradiance caching, all parameters have to be set in advance. You select parameters and then you commit to them. If they do not work, the entire image is lost and you have to try again from beginning.



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RENDERERS BECOMING ECOSYSTEMS

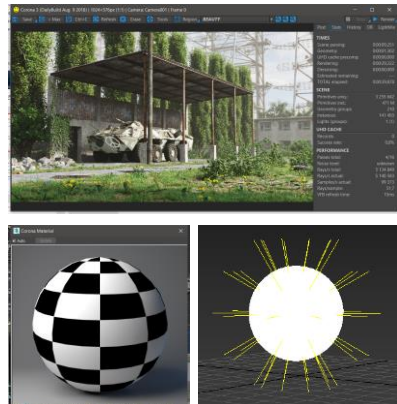
“Or how I forgot the rendering equation”

Next, I want to talk about how the complexity of renderers increased and how they became complex ecosystem, where the actual rendering takes just small part.

HOST APPLICATION ECOSYSTEM

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- Host application with plugin architecture:
 - Rendering plugins
 - Geometry plugins
 - Shader plugins
 - Light plugins
- Common API dictated by host application
- Plugins: blackboxes using the API
- Renderers did just rendering



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To understand what happened here, we first need to look how the situation was few years ago. Corona started as a plugin for 3d studio Max. This and other similar applications have plugin architecture, and there are multiple rendering plugins, geometry plugins, shader plugins, lights, and so on. Basically everything is plugin. The host application glues it all together by providing a common API, and the individual plugins behave as blackboxes.

This has advantage that the renderer can be simple, because it does just the light transport. This is how Corona used to be in the beginning, just the renderer, with single custom material, and custom light object.

ECOSYSTEM PROBLEMS

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- Growing user requirements
- API did not evolve to cover new needs
 - Millions of instances
 - Tracing rays from shaders
- Need for out of the box solution



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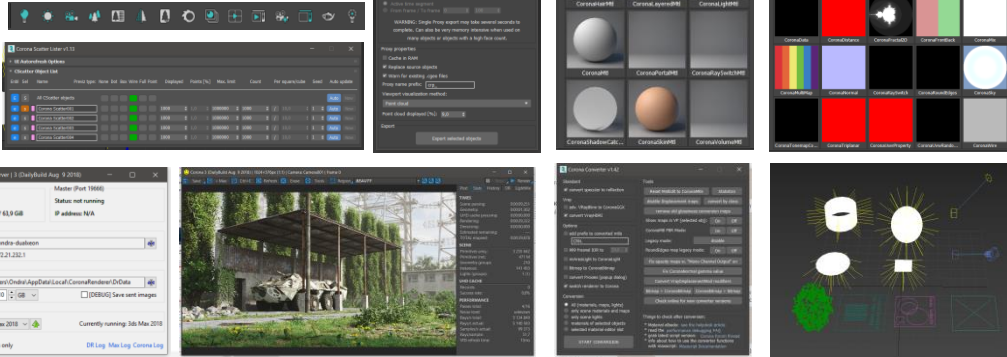
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But we soon encountered more and more problems with this. Users requested more and more features, and some of them were impossible to do in the provided API, because it did not evolve over time to cover these needs. For example for us it was impossible to trace rays from shaders or instance geometry efficiently. Also users don't like when we recommend them some commercial third party solution to their problems, as they would prefer an out of box solution.

RENDERER-CENTRIC ECOSYSTEM

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- Corona now: 44 plugins, 9 executables



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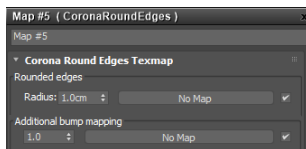
Over time this led us to develop many additional plugins, like custom color picker, object listers, custom geometry proxy, and so on. Overall we now have 44 plugins in 3ds Max and 9 separate applications, and just one of them is the renderer. This slide doesn't even come close to showing everything.

SIMPLICITY VS. FLEXIBILITY

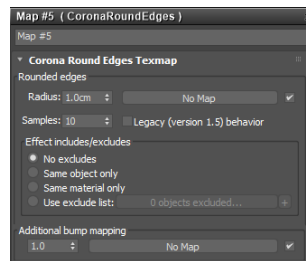
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- Point of conflict in archviz community

Simple UI:



Flexible and powerful shader:



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This brings us new challenges, the most difficult one being whether to choose simplicity or flexibility when adding new tools. For example, when we add new shader: do we create simple, streamlined interface like on left, or do we go for complex interface show on right with lot of multipliers, switches, and so on, covering every possibility?

I think there would be no discussion in VFX, everyone would just go for the version on right, but in archviz, this actually divides the community, and we may have 50% preferring left option, as it is easier to use for novice and non-technical users.

SIMPLICITY VS. FLEXIBILITY

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- Main problem: Render settings
- Artistic controls, workflow improvements
→ apparent complexity increase
- User complaints



Corona Alpha v6
2014



Corona v2
2018



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These issues are most critical in the core render settings, since it is where people historically expect unintuitive parameters. We actually removed such parameters over time, but we were also adding lots of artistic controls and tweaks, such as material overrides, masks, distributed rendering, etc. This caused the render dialog to get longer. Even though the software is now more powerful and easier to use, when you compare the two render settings, the apparent complexity still increased, and we got some negative reactions.

These different UI preferences might be the main limiting factor when trying to create universal renderer for both Archviz and VFX – it would probably need 2 different UIs.

ARCHVIZ ECOSYSTEM NOW

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- Still plugin ecosystem, but renderers dominate
- Users expect additional plugins
- Functionality previously handled by 3rd parties

- Positives:
 - + Closer to the out of the box solution vision
- Negatives:
 - Apparent complexity
 - Defocus from light transport



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So, to sum this up: while we still have the plugin ecosystem, it is now dominated by renderers. And it is expected for renderers to now come with many additional bundled plugins, and to even provide functionality previously provided by third party plugins. This is actually close to the out of the box solution vision, but it also makes the renderers look more complex than they really are, and it is huge distraction for us from improving light transport. We actually spent way more time on the ecosystem lately than on work related to the actual light transport.



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IN-RENDERER POSTPRODUCTION

“Or how we implemented our own little Photoshop sideproject”

There are 2 particular subtopics in the ecosystem that deserve special mention. First is the issue of postproduction, and how it recently moved from 2D applications into renderers.

OLD WORKFLOW

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- Render rough image
- Post: background, foliage, people, details, mood, ...



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In past, the traditional workflow in archviz was to render only rough image, and then photoshop in details such as trees, people, and backgrounds. The tone mapping was also done outside of renderer. This was done at least partially because it was just impossible to render everything with tools back then, but it also produced unique artistic style, as you can see on these images by my colleague.

WORKFLOW NOW

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- Renderer performance, sophistication, assets improved
- In-renderer vegetation, details, people, ... possible



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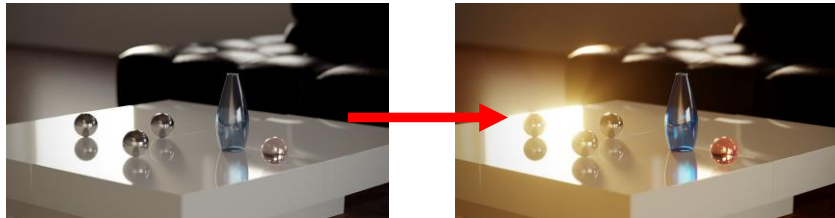
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Now, when the rendering technology improved, it became feasible to just render everything, as shown in these more modern examples. And lot of people started working like this.

WHY IN-RENDERER POST PRODUCTION?

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- Clients want 2-3 times more images per project → more manual labor in 2D
- Photoshopping VR images impossible
- Post production moved into renderer, many new options
 - Custom backplates
 - Tone mapping
 - Lens effects



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The question is, why do people prefer to do as much work as possible directly in the renderer? We investigated this when we noticed just how many postprocessing feature requests we were getting. There are some good reasons reasons. Clients today want more images per project than previously. It is common for 2 or 3 times more images to be delivered per project now, compared to past. So that is 2 or 3 times more time spent in Photoshop in the old workflow. Another good reason is that virtual reality images are now commonly created, and those are impossible to photoshop.

As a result, had to implement various post processing options such as ability to override backgrounds, more advanced tone mapping, and lens effects simulation.

NO-POST (2D APP) WORKFLOW

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- Still more feature requests
- “Just integrate Photoshop”
- Holy Grail for some: “no post processing workflow”



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But nothing we did was enough, people still wanted more. At some point I started asking users if we should just integrate or recreate Photoshop in Corona. I meant it as a joke, but most people said that would actually be perfect for them. Today, at least part of the community adopted something called “no postprocessing workflow”, which really means “no postprocessing in external 2D applications”.

We are OK with providing the extra features, since they are valuable and again fit into our vision of easy to use rendering. The only problem is once again, that this takes us considerable amount of time, that we are not spending on actually improving the light transport.



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FOCUS ON CONTENT CREATION TOOLS

“Or what actually limits the realism?”

Second area I want to highlight are the content creation tools. By this I mean anything that helps creating the scenes to be rendered.

WHAT LIMITS THE REALISM?

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- Rendering no longer limiting
- Models/texture/... the new limit for realism
- Demand for tools simplifying creating assets



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To understand why they became so important, we need to realize one thing: renderers are now so advanced that rendering is no longer limiting the realism of produced images. With this, creating the assets became the new bottleneck. When you can render hundred thousands fully modelled trees with no problems, the only problem you are left with is “where to get good tree models?”. So these tools became one of the most requested and implemented category.

TRIPLANAR MAPPING

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- Simple tool from game industry

Planar UVWs: stretching



Box UVWs: seams



Triplanar mapping: perfect



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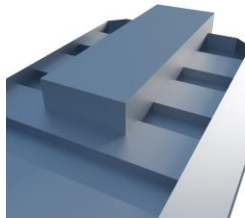
For example, we recently implemented triplanar mapping. This tool known in game industry automatically blends 3 plane-mapped textures together to create seamless, undistorted result, as shown on right. We were totally surprised by the amount of positive feedback we got, given how simple the tool is. We had no idea creating UV mapping was still such huge problem, until we saw how excited users are when they can avoid it.

ROUNDED EDGES

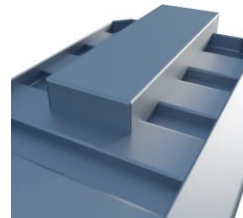
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- Manipulates shading normals
- Creates rounded edges illusion

Base model:



Rounded edges
shader applied:



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Similar story is the rounded edges shader. It modifies the normals of an object at render time to make the edges appear smooth and rounded, as you can see on right. This increases realism since real world edges are almost never razor sharp. This shader again saves incredible amount of time that would be spent manually modelling the roundness of every edge, so even though it is relatively new, it is now a required feature of any competitive renderer.

CONTENT CREATION TOOLS: FUTURE

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- Still more can be done
 - Weather systems
 - Wear & tear, scratches, damage
 - Dirt, water damage
 - UVW mapping, re-topo
 - ...



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There is however more to do. If you wanted to recreate this photo today, you would certainly have hard time. Recreating natural phenomena is still tedious work. We are missing good weather systems, wear&tear, scratches, or anything damaged. UVW mapping can be also problem, since triplanar mapping cannot be used everywhere. There are problems with repairing bad topology on models, and so on. I believe this will require much more research and engineering work to solve.



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RENDERER AS DIGITAL CAMERA

“Or working as a photographer, but only when it suits you”

Now, the final topic is about the most general trend. I asked some artists how they would sum up how the rendering software improved, and they all mentioned that using renderer now feels much more like using a digital camera. This is the biggest, most general change we are seeing in the industry.

CORONA AS DIGITAL CAMERA

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- Suitable algorithms
- No computation/algorithm parameters
- Suitable post processing
- ...



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Many improvements I talked about so far contribute to this. We are now using rendering algorithms that produce better looking results with better control over the result. We minimized number of abstract algorithm parameters which made rendering a one click process. We implemented rich post processing options simulating real cameras and real lenses, and we did much more that I don't have time to go through.

INTERACTIVE RENDERING

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- Mimics real world, encourages exploration
- Corona introduced 3 years ago, now necessary in competitive renderers



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What however deserves special mention is the interactive rendering. In real world, you can see the result before you take the picture, and should be the same when rendering. It encourages exploration and takes guessing and lots of iterations out of the process. Although it is a simple concept, the practical and usable implementation we introduced 3 years ago was unique for that time, mostly because the modelling applications were not ready for this from technical standpoint. Now it is necessity in any successful renderer.

NONPHYSICAL FAKES

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- Still needed for artistic control
- Tricky to implement, unavoidable

Physically correct (color bleeding):



What client wants:



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There are however some limits to this photographic approach. While working as photographers is nice, users don't want to be always constrained by reality, and enjoy the flexibility of non-physical setups, called "fakes". They were once standard to make rendering even feasible, but now we keep just some of them around for flexibility and artistic control.

These are usually tricky to implement and cause lots of problems internally, but unfortunately they are unavoidable. We found out that even if we explain to artists for example why walls in the picture on left are tinted with the floor colors and what is color bleeding, they will not be able to explain that to their client. So the tint has to go, and that means Corona has to support changing materials based on ray type, to produce results shown on right. And there are many similar cases.

LIMITATION: CAUSTICS/COMPLEX LIGHTING

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- No caustics solver in Corona
- Team defocused by creating the ecosystem
- Faking it: caustics missing, but image not ruined
- Known approaches are limiting



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Finally, we need to realize that despite all the progress, rendering is still not a solved problem. For example, in Corona we do not have a working solution for caustics and general complex lighting situations. One of the main reasons for this is that the team was often defocused by the non-light transport side projects I was talking about before. It was not a burning problem in the past, because there are ways to make path tracing fail gracefully in scenes with caustics, by ray intensity clamping. This makes caustics disappear, but the image is not ruined by fireflies. Another reason is, that we are not sure how to compute caustics, since we find the existing approaches limiting.

KNOWN CAUSTICS APPROACHES: LIMITS

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- Bad interaction with nonphysical fakes, AOVs, blackboxes
- Questionable scaling in complex scenes
- Performance in scenes without caustics
- Interactivity (startup time)
- Code complexity (entire ecosystem affected)



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For example, the bidirectional methods make it difficult to preserve all the nonphysical fakes users need. There are also issues with AOVs or render elements, all the 3rd party blackboxes in the plugin architecture, and so on.

The existing approaches also scale badly with scene complexity. Users expect a scene with simple room, and a scene with entire city block to render with about the same speed. Inverse is problem too: advanced methods often bring significant overhead when rendering simple scenes

Another issue is that anything we do must be interactive, meaning the startup time before first pixels are delivered should be in milliseconds.

And finally, advanced light transport algorithms are just hard to implement. Just implementing a paper is not that difficult, but implementing it into a complex ecosystem and making sure it works well with all the other components, and it has consistent performance in any kind of scene users can think of, is entirely different story.



So, to sum up where we are and where we are going

OUR 4 YEARS IN ARCHVIZ

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- Renderers became complex ecosystems
 - Touching every aspect of content creation, rendering, and postproduction
- We made rendering feel like taking pictures with DSLR
 - Splotch and artifact-less
 - Settings-less
 - Interactive
- Caustics missing



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In last 4 years renderers became their own ecosystems, with advanced shaders and content creation tools. Numerous advances in rendering algorithms and user interfaces made rendering feel like taking pictures with digital camera, by making the output images artifact-free, having software with no settings, and being fully interactive. But we were not able to solve the problem of caustics, because the existing approaches do not particularly fit our needs. I believe we need more research to solve this problem.

OUR NEXT 4 YEARS

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- Continue in direction of "Digital camera feel"
- Help with content creation
- Biggest single challenge: production ready, fully-automatic, fast caustics



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Our goals for the next 4 years are to continue in the direction of photographic workflows. We want to particularly improve the speed, tonemapping, and quality of shaders. We also want to add more tools that help with content creation, as we recognize their value for users. But the biggest challenge we will face is definitely being able to render caustics exactly the same way everything else is rendered in Corona - having no parameters users have to tweak, being always on, fully compatible, and reasonably fast.