Status of the **L**ayer-**B**ased **S**VG **E**ngine in WebKit

Web Engines Hackfest 2024

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A short introduction

The LBSE work is a joint effort:

- Nikolas Zimmermann, Igalian since 2019 - located in Germany
- Rob Buis, Igalian since 2017 - located in Ireland

- Founders of kdom, kcanvas, ksvg2/khtml2
- khtml contributors since 2001
- WebKit contributors since 2005
- WebKit reviewers since February 2007

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Topics

1) Introduction to LBSE

2) Upstreaming status

3) Outlook

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1) Introduction to LBSE

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What is LBSE?

Layer-Based SVG Engine

- Codename for new SVG engine in WebKit
- Started as **Proof-Of-Concept** in **September 2019**
- Goal: resolve architectural issues present since 15+ years
- Developed by Igalia, funded by Igalia, Vorwerk and Wix.

What is LBSE?

Layer-Based SVG Engine

- Enable hardware-accelerated compositing / hardware-accelerated transform animations
- Enable 3D transform support for arbitrary SVG content, unlock perspective transformations
- Unify HTML/SVG rendering pipelines, which are mutually exclusive at present
- **Proof-Of-Concept** patch passed all existing layout tests in **October 2021** (1)
- Performance comparable to legacy engine in e.g. MotionMark (2)

(1) Compositing/z-index/will-change/... was only tested in most basic scenarios for SVG.

(2) MotionMark suffers from layer overhead ⟶ LBSE ~2-4% slower.

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How is it achieved?

- Let SVG participate in the layer tree, which handles compositing, 3D transformations, etc. for HTML/CSS.
- Remove knowledge about transform handling out of the SVG renderers.
- Remove SVG specific clipping/marker/masking/filter code
- Redesign SVG render tree to be convenient for the existing CSS code.
  (Coordinate system decisions, etc.)
- Reuse as much as code possible in RenderLayer - without SVG specific changes.

Evolution since 2021

The "final" version of the prototype was a **drop-in replacement** for the old SVG engine.

During and after the WebKit contributors meeting 2021, a plan was established how LBSE can be integrated into WebKit, without violating the usual high standards with respect to reviewability.

As a consequence...

- No way to use any existing patch as-is from LBSE downstream
- Lots of manual work necessary.
- It is equal to **yet another** rewrite.

Upstreaming plan

It was decided to bring-up LBSE in small, reviewable atomic pieces **in parallel** to the legacy SVG engine, share code where it makes sense, and split elsewhere.

All the code is behind a compile-time flag **`ENABLE(LAYER_BASED_SVG_ENGINE)`** and an additional setting **`LayerBasedSVGEngineEnabled`** that can be used to toggle between LBSE and the legacy SVG engine **at runtime**.

⟶ Upstreaming started Dec 2021

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Let's have a look at the current status...

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2) Upstreaming status

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Progress tracking

The bug report **"#90738 - Harmonize HTML & SVG rendering"** tracks the upstreaming status in WebKit Bugzilla; individual commits are tracked on **"GitHub WebKitIgalia #1"**.

- 161 patches so far directly related to LBSE
  (first: **29. November 2021**, current: **10. April 2024**).
- Overall status ~ **87%**

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Achievements

Since the last WebKit Contributors Meeting in 2023, two major tasks were finished. This work was funded by Wix, bringing LBSE closer to a shipable state.

For more details, see the blog post **https://wpewebkit.org/blog/status-of-lbse-in-webkit.html**.

1) Re-design resource invalidation logic
2) Implement all SVG resources for LBSE

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What is a SVG resource?

```
<defs>
    <linearGradient id="aGradient">
        <stop offset="10%" stop-color="blue"/>
        <stop offset="90%" stop-color="green"/>
    </linearGradient>

    <clipPath id="aClip">
        <circle cx="50" cy="50" r="50"/>
    </clipPath>
</defs>

<rect width="100" height="100" fill="url(#aGradient)" clip-path="url(#aClip)"/>
```


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Status of resources in October 2023

- LBSE support solids fill / stroke operations for shapes / text ✅
- **No support** for gradients / patterns / markers
- **No support** for clipping / masking
- **No support** for filters

Our plan was to redesign the resource handling, avoiding **design mistakes** from the legacy SVG engine, and offering support for all SVG painting features in an unified way for **both** HTML elements and SVG elements.

⚠️ Caveat: We can not **easily** re-use the resource logic from the legacy SVG engine... ⚠️

Legacy SVG engine design issues

Resource invalidation is **fundamentally broken** in the legacy SVG engine.

Example: A **<mask>** is applied to a **<path>**, and a child of that **<mask>** references a **<clipPath>**.

DOM tree

```
<defs>
  <clipPath id="clip">
    <circle r="10"/>
  </clipPath>
  <mask id="mask">
    <rect x="5" clip-path="url(#clip)"/>
  </mask>
</defs>
<path mask="url(#mask)"/>
```

Render tree

```
RenderSVGHiddenContainer ("defs")
    RenderSVGResourceClipper ("clip")
        RenderSVGEllipse ("circle", r=10)

    RenderSVGResourceMasker ("mask")
        RenderSVGRect ("rect", x=5) | uses "clip" resource


RenderSVGPath ("path") | uses "mask" resource
```


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Legacy SVG engine design issues

How to handle nested invalidations?

An early design decision was to re-use the `layout()` logic of the render tree to handle resource invalidations. Consider changing the radius to **20** dynamically from JavaScript.

What happens?

Render tree

```
RenderSVGHiddenContainer ("defs")
    RenderSVGResourceClipper ("clip")
        RenderSVGEllipse ("circle", r=10)

    RenderSVGResourceMasker ("mask")
        RenderSVGRect ("rect", x=5) | uses "clip" resource


RenderSVGPath ("path") | uses "mask" resource
```


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1. Parse attribute in `SVGCircleElement`, update presentational style and trigger style invalidation.
2. During style resolving `RenderSVGEllipse` receives a new style with a changed radius requiring a re-layout, which is triggered asynchronously.
3. The resources in the ancestor chain are notified about the style change, clients of resources are invalidated **recursively**. `RenderSVGRect` is marked for layout, followed by `RenderSVGPath`.
4. After style resolving finished, a render tree re-layout is triggered asynchronously.

Render tree

```
RenderSVGHiddenContainer ("defs")
    RenderSVGResourceClipper ("clip")
        RenderSVGEllipse ("circle", r=10)

    RenderSVGResourceMasker ("mask")
        RenderSVGRect ("rect", x=5) | uses "clip" resource


RenderSVGPath ("path") | uses "mask" resource
```

→ Unnecessary `layout()` for subtrees containing resources, **expensive** tree walks, etc.

Resource handling redesign

Relevant call graphs:

1. JS calling `setAttribute(...)`, triggering the invalidation chain.

```
frame  #0: `WebCore::Element::invalidateStyle(this=0x0000000164011d60)
frame  #1: `WebCore::SVGElement::setPresentationalHintStyleIsDirty(this=0x0000000164011d60)
frame  #2: `WebCore::SVGCircleElement::svgAttributeChanged(this=0x0000000164011d60)
frame  #3: `WebCore::SVGElement::attributeChanged(this=0x0000000164011d60)
frame  #4: `WebCore::SVGGraphicsElement::attributeChanged(this=0x0000000164011d60)
frame  #5: `WebCore::SVGGeometryElement::attributeChanged(this=0x0000000164011d60)
frame  #6: `WebCore::SVGCircleElement::attributeChanged(this=0x0000000164011d60)
frame  #7: `WebCore::Element::notifyAttributeChanged(this=0x0000000164011d60)
frame  #8: `WebCore::Element::didModifyAttribute(this=0x0000000164011d60)
frame  #9: `WebCore::Element::setAttributeInternal(this=0x0000000164011d60)
frame #10: `WebCore::Element::setAttribute(this=0x0000000164011d60)
frame #11: `WebCore::jsElementPrototypeFunction_setAttributeBody(this=0x000000016f371b88)::...
```


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Resource handling redesign

2. `RenderSVGEllipse` is marked for layout (as consequence of the previous style invalidation)

```
frame  #0: WebCore::RenderObject::setNeedsLayout(this=0x00000001640056a0)
frame  #1: WebCore::RenderObject::setNeedsLayoutAndPrefWidthsRecalc(this=0x00000001640056a0)
frame  #2: WebCore::RenderElement::styleDidChange(this=0x00000001640056a0, diff=Layout, oldStyle=...)
frame  #3: WebCore::LegacyRenderSVGModelObject::styleDidChange(this=0x00000001640056a0, diff=Layout, old
frame  #4: WebCore::RenderElement::setStyle(this=0x00000001640056a0, ...)
frame  #5: WebCore::RenderTreeUpdater::updateRendererStyle(this=0x000000016f374b50, ...)
frame  #6: WebCore::RenderTreeUpdater::updateElementRenderer(this=0x000000016f374b50, ...)
frame  #7: WebCore::RenderTreeUpdater::updateRenderTree(this=0x000000016f374b50, ...)
frame  #8: WebCore::RenderTreeUpdater::commit(this=0x000000016f374b50, ...)
frame  #9: WebCore::Document::updateRenderTree(this=0x0000000116145a00, ...)
frame #10: WebCore::Document::resolveStyle(this=0x0000000116145a00, ...)
frame #11: WebCore::Document::updateStyleIfNeeded(this=0x0000000116145a00)
```

Resource handling redesign

Relevant call graphs:

3. `RenderSVGRect` is marked for layout (as it uses mask, which uses clip, which got modified)

```
frame  #0: `WebCore::RenderObject::setNeedsLayout(this=0x0000000164005980, markParents=MarkContainingBl
frame  #1: `WebCore::RenderSVGResource::markForLayoutAndParentResourceInvalidation(object=0x000000016400
frame  #2: `WebCore::LegacyRenderSVGResourceContainer::markAllClientsForInvalidation(this=0x000000016400
frame  #3: `WebCore::LegacyRenderSVGResourceClipper::removeAllClientsFromCache(this=0x0000000164005520)
frame  #4: `WebCore::RenderSVGResource::markForLayoutAndParentResourceInvalidation(object=0x000000016400
frame  #5: `WebCore::SVGResourcesCache::clientStyleChanged(renderer=0x00000001640056a0, diff=Layout, old
frame  #6: `WebCore::LegacyRenderSVGModelObject::styleDidChange(this=0x00000001640056a0, diff=Layout, ol
frame  #7: `WebCore::RenderElement::setStyle(this=0x00000001640056a0, ...)
frame  #8: `WebCore::RenderTreeUpdater::updateRendererStyle(this=0x000000016f374b50, ...)
...
frame #14: `WebCore::Document::updateStyleIfNeeded(this=0x0000000116145a00)
```


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⚠️ Calling `setNeedsLayout` from within `layout` is evil and inefficient. ⚠️

Furthermore the *correctness* of the invalidation chain depends on the **element order** in DOM.

This is known since a long time, dating back to at least 11 years ago:

Bug #81515 - SVG Resources layout needs refactoring
Bug #179788 - Make RenderSVGResource::markForLayoutAndParentResourceInvalidation() more robust
Bug #207451 - RenderSVGShape invalidates all its resources when it needs layout, but is that necessary?
Bug #208903 - [SVG] RenderSVGResourceContainer's style invalidation should be a pre-layout task
Bug #242420 - ☂️ avoid invalidating SVG resources when referencing element changes layout

...

Plan presented during WebKit Contributors Meeting in October 2023:

1) Re-design resource invalidation logic
2) Implement all SVG resources for LBSE

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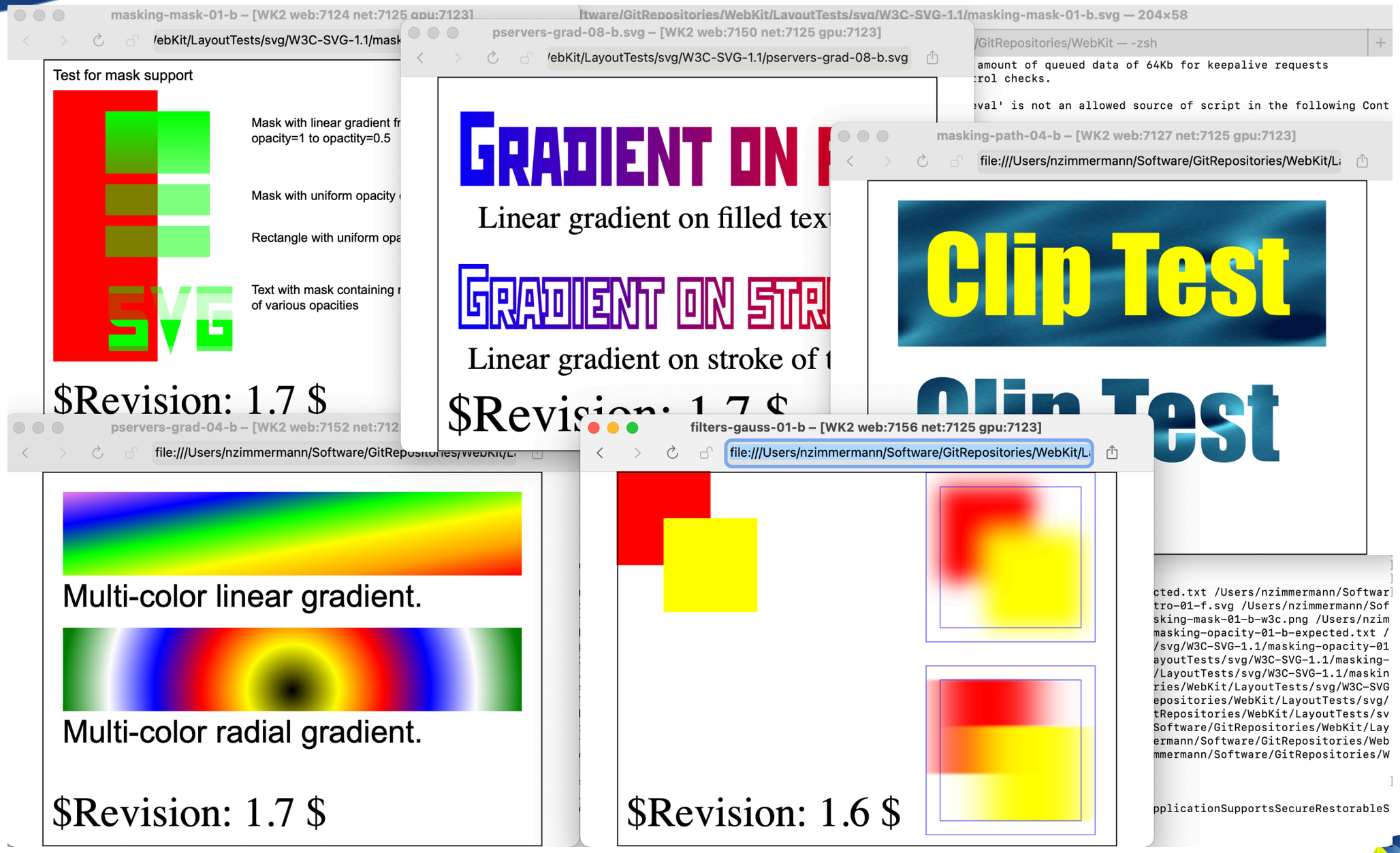
Status 2024

1) Re-design resource invalidation logic ✅

A new approach, re-using similar logic from CSS invalidation, was implemented.
All code landed upstream.

2) Implement all SVG resources for LBSE ⏳

- LBSE support solids fill / stroke operations for shapes / text ✅
- Complete support for gradients / patterns / markers ✅
- Complete support for clipping / masking ✅
- Complete support for filters ⏳ (under review)


masking-mask-01-b – [WK2 web:7124 net:7125 gpu:7123]
Test for mask support
Mask with linear gradient fr
opacity=1 to opactity=0.5
Mask with uniform opacity
Rectangle with uniform opa
Text with mask containing
of various opacities
SVG
$Revision: 1.7 $
pservers-grad-08-b.svg – [WK2 web:7150 net:7125 gpu:7123]
Linear gradient on filled tex
Linear gradient on stroke of
$Revis
masking-path-04-b – [WK2 web:7127 net:7125 gpu:7123]
Clip Test
Clip Test
pservers-grad-04-b – [WK2 web:7152 net:712
Multi-color linear gradient.
Multi-color radial gradient.
$Revision: 1.7 $
filters-gauss-01-b – [WK2 web:7156 net:7125 gpu:7123]
$Revision: 1.6 $

3) Outlook

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Short-term

- ⚠️ Ensure funding for LBSE work. ⚠️
  We need more partners that help us to get LBSE across the finish line.
- Finish `<filter>` work (Apple).
- Finish `<text>`/`<tspan>` related repainting issues
- Verify invalidation is complete for all SVG resources, used in HTML/SVG contexts.
- Perform security audit: fuzzing, ASAN -- try the whole arsenal.

Long-term

- ⚠️ Ensure funding for LBSE work. ⚠️
- Finish LBSE implementation, such that all layout tests pass.
- Ensure LBSE is at least as fast as the legacy engine in any standard benchmark.
  - Reduce RenderLayer overhead.
  - Selectively construct RenderLayers only if necessary.
  - … (there are more ideas in the pipeline, that need testing)
- Final task: Turn on LBSE by default. Remove legacy SVG engine.

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Thanks for your attention!

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