Assistive Technologies for STEM Subjects From Bitmap Graphics to Fully Accessible Chemical Diagrams

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The Future of STEM Content

- Like for most content the future is the Web
  - Ubiquitous
  - Flexible
  - Adaptable
  - Independent
  - And: quick and easy to publish
- Two issues (also for accessibility):
  - Lack of web support for STEM
  - Proliferation of short lived content

Problems with STEM Content on the Web

- Full of specialist notations, formulas, diagrams, charts, etc.
- Authors do not understand the web: Content is geared towards print.
- This makes it already difficult to work with in standard use cases let alone in the accessibility use case.

- So what do we need?
- Specialist web standards for all types of STEM content:
  - Chemistry, Biology, Computer Science, ...
  - From STEM to STEAM: Music, Manuscripts, ...

NO! We do not need specialist web standards!

A Warning Example: The Failure of MathML on the Web

- MathML is officially part of the HTML5 standard
- Mathematics should be formatted in (presentation) MathML.
- Generally this is not the case: Instead it is given as LaTeX or ASCIIMath.
- MathML has very limited support from Browser vendors
  - Two incomplete implementations: FireFox (Gecko), Safari (WebKit)
- MathML spec is seriously outdated
  - Refuses to take modern web technology into account!

The Role of Polyfill Solutions

- With technologies like SVG, HTML5/Canvas, CSS/Houdini, there are (nearly) unlimited possibilities to shape web content
- There is no need and no desire for specialist standards
- Specialist content will be treated more and more by bespoke, but universal rendering solutions: Polyfills
- MathJaX is an example that has filled the need for Mathematics rendering
- Others include graphics libraries like: JSxGraph, D3js,. . .

What about Accessibility?

- Semantics has to be provided regardless of the underlying implementation
- WCAG 2.0 is not sufficient: work on more ARIA, standard APIs, etc.
- Polyfills start using Universal design principles
- This can solve the problem of making ephemeral material accessible

Accessibility of STEM Material

- In the light of a fleeting medium like the Web traditional techniques fail
  - Audio recordings, tactile graphics, German film, Physical Models, Specialist translation service
- Lack of timeliness
- Often lack of resources in the real world
- But web is ideal to further learner independence

Case Study on (Chemical) Diagrams

- Diagrams are very important for teaching STEM subjects
  - Geometry, Physics, Chemistry, Biology, ...
- Chemical diagrams (depictions of molecules) are ubiquitous in teaching material on chemistry, biosciences, life sciences.
  - GCSE and A-levels teaching
  - undergrad curriculum
  - research publications

Accessibility of Digital Diagrams

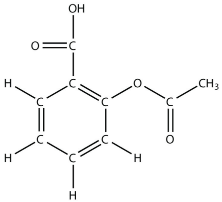
- Bitmaps are simply inaccessible and ALT texts are generally not enough
- Overlay bitmaps for tactile or touch exploration
- SVG with screen reading software
  - Need to be carefully designed and structured
  - Often requires diagrams to be drawn in particular way or authoring environment
  - Need for specialist software to access and interact with diagrams
  - Additional hurdles for both authors and readers

Goals

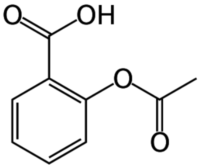
- Make regular teaching material accessible without the need to create new resources
- From inaccessible image to support for independent learning
- Source independence
  - Do not rely on the benevolent, educated author
- Tool independence
  - Do not require users to install/learn/use a specialist too.
- Provide a seamless user experience without/very little interface
- (Ideally) accessible with all browsers, screen readers
- Use standard web technology (HTML5, SVG, JavaScript)
- Support diverse material, for novices and experts alike

Examples

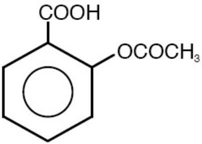
- Already Chemistry diagrams come in a variety of flavours depending on author preference and intended audience
- Different representations of Aspirin molecule.



Displayed formula.



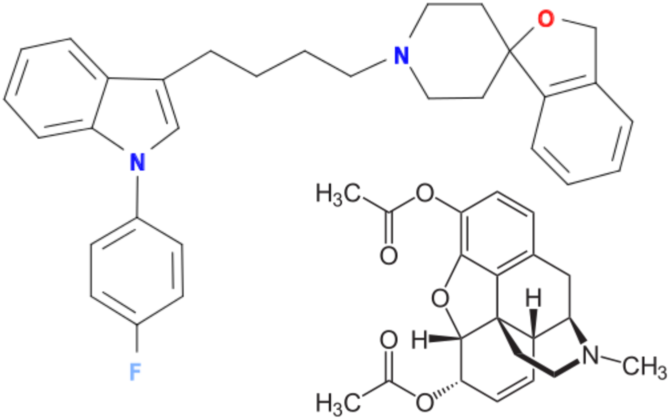
Skeletal formula.



Structural formula.

Examples

- Or somewhat more complex.



End-to-end Procedure from Images to Accessible Diagrams

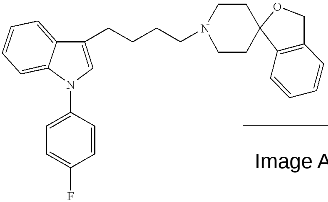
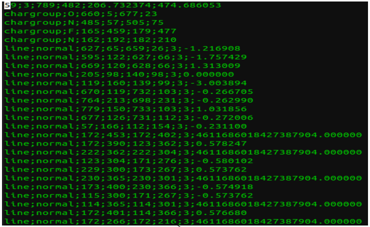


Image Analysis



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chargroup;O;660;5;677;23
chargroup;N;485;57;505;75
chargroup;F;165;459;179;477
chargroup;N;162;192;182;210
line;normal;627;65;659;26;3;-1.216908
line;normal;595;122;627;66;3;-1.757429
line;normal;669;120;628;66;3;1.313009
line;normal;205;98;140;98;3;0.000000
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line;normal;779;150;733;103;3;1.031856
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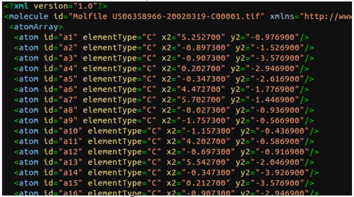
Image Recognition



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  <atom id="a2" elementType="C" x2="-0.897300" y2="-1.526900"/>
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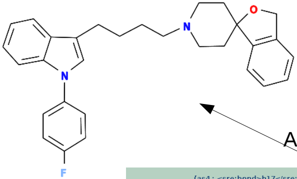
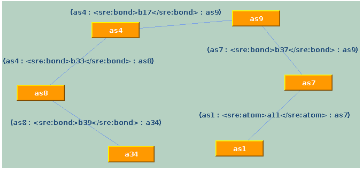


Accessible Rendering



Semantic Enrichment

Procedure

Input: A bitmap image of a molecule diagram

1. Image analysis and segmentation
2. Diagram recognition
3. Generation of annotated SVG
4. Semantic enrichment
5. Accessible diagram via browser front-end

Image Segmentation

Based on system we initially implemented for diagram recognition on patent databases

- Initial pre-processing: Binarisation, noise reduction...
- Connected component extraction and labelling
- Optical Character recognition and removal
- Thinning and smoothing with Douglas-Peuker
- Separation of bond elements
  - Walk skeleton diagram structure
  - Identify and break junction points
- Result is a set of geometric primitives:
  Character groups, lines, bold lines, circles, triangles

Diagram Recognition

- Rule based system
- Rewrites bag of geometric primitives into a graph representation
- Example:
  1. Let l_1, l_2 be distinct line segments of a minimum length.
  2. If l_1 is nearly parallel to and in a neighbourhood of l_2.
  3. No other line segment is nearly parallel to l_1 or l_2.

  $\Rightarrow$ Then (l_1, l_2) form a double bond.

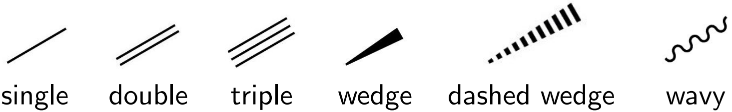


Diagram Recognition (ctd.)

- Not straight forward mapping of primitives to graph elements
- Also rewriting of primitives into other primitives
- Example of implicitly given carbon atoms

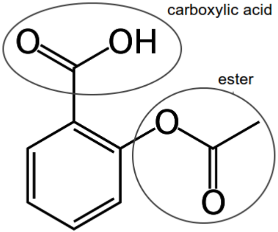
- Result is a Chemical Markup File (CML or MOL)
- But it is still a "flat" representation of a molecule

Annotated SVG Generation

- Many solutions for generating SVG from chemical markup
- But they only draw!
- And in the process destroy any structure or chemical knowledge
- Build our own SVG generator with emphasis on
  - Grouping meaningful units together (e.g., double bonds)
  - Retaining names given to components in the chemical markup (IDs of atoms, bonds, etc.)
- Result annotated and grouped SVG

Semantic Enrichment

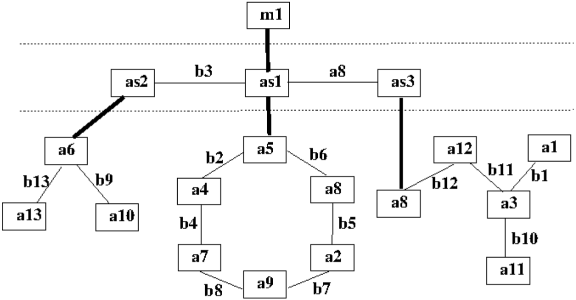
- Take basic chemical markup: Enrich it with derived knowledge and structure it accordingly
- Uses some cheminformatics algorithms from the CDK
- Detect major building blocks of the molecule
  - Aliphatic chains
  - Ring systems: Isolated and fused
  - Functional groups



- Order blocks and atoms by chemical conventions

Abstraction Graph

- Represent molecule as multi-layered graph
- 3-4 layers of abstraction



- Molecule
- Block
- Atom

- Additional layer in case of fused ring systems

Generating Descriptions

- Generate low level descriptions for atoms, bonds, and positions.
- High level descriptions for block elements:
  - Expert descriptions: Automatically name chemical compounds via ChemSpider and Cactus webservices
  - Basic descriptions via atoms, bonds, and substitutions
- Add abstraction graph and descriptions to original CML representation.

- Result semantically enriched CML File

Accessibility Support

- Graph structure can serve as the bases for interacting with the molecule
- Enables hierarchical exploration of molecule and its components
- Very simple navigation model: down/up, right/left
- Screen Reader Support:
  - Generate speech output from CML annotations on different levels
  - Display of speech output using subtitling
- Low Vision/Learning Disability Support:
  - Highlighting of inspected components
  - Optional zooming and magnification of components
  - Changing contrast, colour configurations

Browser Front-end

Generic browser front-end using standard web technology:

- Ajax service to import
  - annotated SVG
  - enriched CML as XML object
- Some JavaScript to tie it all together.
- WAI-ARIA and CSS to implement interactive exploration

Browser Front-end (Implementation)

- Container element for SVG and CML/XML document
  - `role` application with an appropriate `aria-label`
  - Both SVG and XML are `aria-hidden`
- Speech output for screen readers
  - Computation of speech string from CML components
  - Updating content of an `assertive` `aria-live` region
- Magnification and highlighting of explored substructures
  - Zooming by changing SVG view port
  - Highlighting by changing CSS properties
- Low vision and dyslexia support
  - Contrast changes by changing CSS properties

Browser Front-end (User Experience)

- Navigatable molecule is announced and can be entered on key
- Walk the CML structure using arrow keys
- Additional keys for special functionality (e.g., change of contrast)
- Execute visual and audio effects on the SVG
- Give the reader the feel of interacting with the diagram

User Feedback and Testing

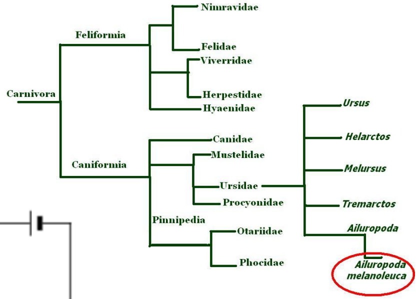
Ongoing stake holder involvement throughout development

- input from blind chemist (Duncan Bell)
- explanations tested in regular classroom teaching
- “Phone-experiments” with chemistry researchers
- “Molimod testing” with students at various levels in specialist college (NCW)
- Low vision support testing with A-level students
- Testing with educators for visually impaired children.

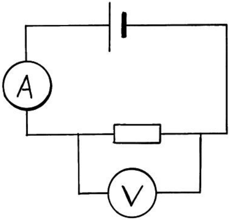
Current Work

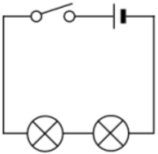
- Implementation of Touch Events
- Tactile diagrams, 3D printing, Localisation

- Extension to Biology (phylogenetic trees)



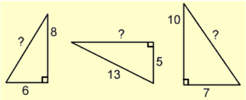
- Physics (circuit diagrams)

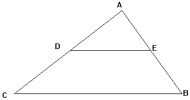


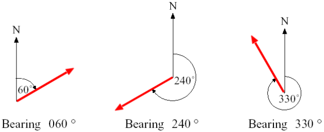


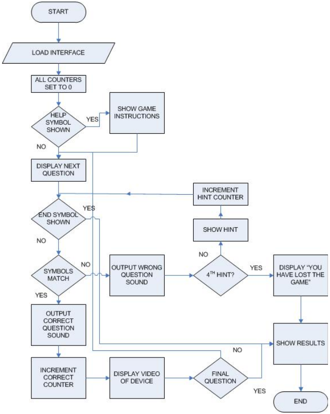
Future Work

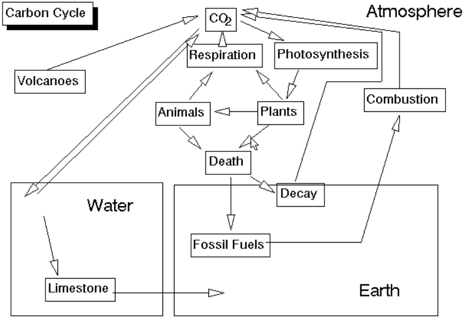
- Other STEM subjects: Maths (geometry, bearings), Biology (systems diagrams), Computer Science (flow charts)











Conclusions

- End-to-end procedure from images to accessible diagrams
  - WAI-ARIA needs to be expanded and become more flexible
  - Example: current work of the W3C SVG-4-A11Y task force
- No need to rely on author cooperation
- Integrates seamlessly without need for bespoke tools
- Works with most combinations of platforms, browsers, screen readers
  - Standardised interfaces in the Assistive Technology Ecosystem: screen readers, magnifiers, braille displays, ...
- Demo of web front end

  `http://progressiveaccess.com/chemistry`

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