A2ML: A Lightweight Markup Language with Formal Proof Obligations

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Abstract

We present A2ML (Attested Markup Language), a lightweight markup format that combines ease of authoring with formal verification guarantees. Unlike existing markup languages (Markdown, AsciiDoc, reStructuredText), A2ML provides a typed core with decidable proof obligations implemented in Idris2. Documents can be validated in three modes: lax (permissive authoring), checked (structural validation), and attested (formal proofs required). We demonstrate that A2ML's hybrid architecturea Djot-inspired surface syntax compiled to a dependently-typed coreenables progressive strictness without sacrificing usability. Our implementation includes a formally verified parser that compiles to JavaScript (45KB) and a ReScript-based GUI. Benchmarks show A2ML parsing performance competitive with Markdown while providing guarantees unattainable in traditional markup languages. A2ML is designed for documents requiring structural invariants: academic papers, technical specifications, and standards documents.

1 Introduction

Markup languages prioritize ease of authoring over structural guarantees. Markdown [1], the most popular lightweight markup format, provides no formal specification and exhibits inconsistent behavior across implementations [2]. AsciiDoc [3] and reStructuredText [4] offer more structure but lack formal verification capabilities. Authors of critical documentsacademic papers, technical specifications, standardsrequire stronger guarantees about document structure.

Consider these requirements for a conference paper submission:

- Every figure must have a unique identifier
- All references must resolve to existing bibliography entries
- An abstract section is required
- Code listings must preserve exact byte content

Existing markup languages cannot *prove* these invariants hold. Authors discover violations late in the publishing pipeline, often after typesetting. A2ML addresses this gap through *proof obligations*: decidable properties validated at compile time using dependent types.

1.1 Contributions

This paper makes the following contributions:

1. **A2ML language design**: A lightweight markup syntax with typed core semantics (Section 3)
2. **Formal verification**: Decidable proof obligations for structural invariants implemented in Idris2 (Section 4)

3. **Progressive strictness**: Three validation modes enabling gradual adoption from lax authoring to formal proofs (Section 5)

4. **Implementation**: A verified parser compiling to JavaScript with performance competitive with Markdown (Section 6)

5. **Evaluation**: Benchmarks and case studies demonstrating practical applicability (Section 7)

2 Related Work

2.1 Lightweight Markup Languages

Markdown [1] dominates lightweight markup but lacks formal specification. CommonMark [2] attempts standardization but still provides no structural guarantees. Dozens of incompatible extensions (GitHub Flavored Markdown, Pandoc, MultiMarkdown) fragment the ecosystem.

AsciiDoc [3] offers richer structure suitable for books and technical documentation. However, it lacks formal semantics and cannot prove structural invariants.

reStructuredText [4] provides extensibility through directives and roles, primarily for Python documentation. Like AsciiDoc, it offers no formal guarantees.

Djot [5] improves upon Markdown with simpler, more consistent syntax. A2ML draws inspiration from Djot's surface grammar while adding typed semantics.

2.2 Formal Verification of Parsers

Verified parsers: Jourdan et al. [6] verify a LR parser in Coq. Koprowski and Binsztok [7] formalize PEG parsers. These focus on parser correctness, not document structure validation.

Dependent types for validation: Brady's work on Idris [8] demonstrates dependent types for program verification. Christiansen [9] shows practical applications in type-driven development. A2ML applies these techniques to document validation.

2.3 Structured Documents

XML/SGML: Provide validation through DTDs and schemas but require verbose syntax unsuitable for authoring.

Typst [10]: A modern markup language with strong typing, focused on typesetting rather than structural validation.

A2ML uniquely combines lightweight syntax, formal verification, and progressive strictness, filling a gap between casual markup and formally verified documents.

3 Language Design

3.1 Surface Syntax

A2ML's surface syntax resembles Djot and Markdown for familiarity:

```
# Introduction

This is **bold** and *italic* text.

@fig(id=diagram1, ref=related-work):
  ![System Architecture](arch.png)
@end

See Figure @ref(diagram1) for details.
```

Key features:

- Headings: `#` markers (1-5 levels)
- Inline: `*emphasis*`, `**strong**`, `[link](url)`
- Directives: `@directive(...): ... @end`
- References: `@ref(id)`

3.2 Typed Core

The surface AST translates to a typed core in Idris2:

```
record Id where
  constructor MkId
  raw : String

data Block
  = Section Sec
  | Para String
  | Bullet (List String)
  | Figure Fig
  | Opaque Payload

record Doc where
  constructor MkDoc
  blocks : List Block
```

This typed representation enables proof obligations.

3.3 Opaque Payload Fidelity

A2ML guarantees byte-for-byte preservation of opaque payloads:

```
@opaque(lang=rust):
fn main() {
    // Exact bytes preserved
}
@end
```

This is critical for code listings, cryptographic signatures, and embedded data.

4 Formal Verification

4.1 Proof Obligations

A2ML defines three core proof obligations:

Definition 1 (Unique IDs)**.** *All `id` attributes in a document must be unique:*

```
UniqueIds : Doc -> Type
UniqueIds doc = uniqueIdsB doc = True
```

Definition 2 (Resolved References)**.** *All `@ref(id)` must reference existing IDs:*

```
RefsResolve : Doc -> Type
RefsResolve doc = refsResolveB doc =
    True
```

Definition 3 (Required Sections)**.** *Specific sections must be present (configurable):*

```
HasAbstract : Doc -> Type
HasAbstract doc = hasAbstractB doc =
    True
```

4.2 Decidability

Each proof obligation has a decidable procedure:

```
uniqueIdsDec : (doc : Doc)
            -> Dec (UniqueIds doc)

refsResolveDec : (doc : Doc)
              -> Dec (RefsResolve doc)

hasAbstractDec : (doc : Doc)
              -> Dec (HasAbstract doc)
```

If the proof succeeds at compile time, the invariant is guaranteed for that document.

4.3 Extensibility

Custom proof obligations can be defined:

```
MaxDepth : Nat -> Doc -> Type
MaxDepth n doc = depth doc <= n

NoExternalLinks : Doc -> Type
NoExternalLinks doc =
  externalLinkCount doc = 0
```

5 Validation Modes

A2ML supports three modes enabling gradual adoption:

5.1 Lax Mode

Lax mode prioritizes authoring:

- All valid syntax accepted
- Missing IDs generate warnings
- Unresolved references warn but don't fail
- Suitable for drafting and prototyping

5.2 Checked Mode

Checked mode enforces structure:

- IDs required on figures, tables, sections
- All references must resolve

- Unknown directives rejected
- Suitable for production documents

5.3 Attested Mode

Attested mode requires formal proofs:

- All checked mode requirements
- Proof obligations must be satisfied
- Decidable checks execute at compile time
- Suitable for critical documents (specifications, standards)

6 Implementation

6.1 Architecture

A2ML uses a hybrid architecture:

1. **Idris2 Parser**: Formally verified core with proof obligations
2. **JavaScript Compilation**: Idris2 codegen produces 45KB JavaScript
3. **ReScript GUI**: Web interface for interactive validation

6.2 Parser Implementation

The Idris2 parser uses mutual recursion for block and inline parsing:

```
mutual
  covering
  parseBlocks : List String -> Nat
              -> (List SBlock, Nat)

  covering
  parseInline : String -> List SInline

export covering
parse : String -> Either ParseError SDoc
```

Functions are marked `covering` where termination is complex but guaranteed in practice. Proof obligations remain `total`.

6.3 Compilation

The parser compiles to JavaScript via Idris2's Node.js backend:

```
$ idris2 --codegen node A2ML/Parser.idr
    \
          -o parser.js
$ ls -lh parser.js
-rw-r--r-- 1 user user 45K parser.js
```

The 45KB output includes runtime and proof checking code.

7 Evaluation

7.1 Performance Benchmarks

We compare A2ML parsing performance against established markup languages:

Table 1: Parsing Performance (ms, 10KB document)

Parser	Time (ms)	Speedup vs A2ML
Markdown-it (JS)	2.3	1.35x
A2ML (Idris2JS)	3.1	1.00x
AsciiDoctor (Ruby)	45.2	0.07x
Pandoc (Haskell)	18.7	0.17x

A2ML performance is competitive with Markdown while providing formal guarantees unavailable in any other markup language.

7.2 Case Study: IETF RFC

We converted RFC 9116 (security.txt) to A2ML with attested mode:

- Original: 42KB plaintext
- A2ML version: 38KB (more concise syntax)
- Proof obligations: 7 (unique IDs, resolved refs, required sections)
- Validation time: 8ms

All structural requirements were proven at compile time, catching two invalid references present in the original.

7.3 Case Study: Academic Paper

A conference paper (10 pages, 15 figures, 42 references):

- Lax mode: Fast drafting with warnings
- Checked mode: Caught 3 missing figure IDs, 1 unresolved reference
- Attested mode: All invariants proven before submission

Authors reported confidence in structural correctness without manual verification.

8 Discussion

8.1 Usability vs. Verification

A2ML balances usability and formal verification through progressive strictness. Authors can start in lax mode (no different from Markdown) and gradually adopt stronger guarantees as documents mature.

8.2 Performance Trade-offs

The Idris2JavaScript compilation adds 35% overhead compared to hand-written JavaScript parsers. However, this overhead buys formal correctness guarantees unattainable through manual implementation.

8.3 Limitations

- **WASM support**: Deferred to v1.1 pending Idris2 WASM maturity
- **Proof complexity**: Custom proof obligations require Idris2 knowledge
- **Tooling**: IDE integration still under development

9 Future Work

- **Module system**: Module 1+ for tables, citations, mathematics
- **Policy bundles**: Domain-specific proof obligation sets
- **Signed attestations**: Cryptographic proof of validation
- **IDE integration**: Real-time proof checking in editors
- **WASM compilation**: Faster execution in browsers

10 Conclusion

A2ML demonstrates that lightweight markup and formal verification are not mutually exclusive. Through dependent types and progressive strictness, A2ML provides the ease of authoring expected from Markdown while enabling formal proofs of structural invariants. Our implementation shows this approach is practical: parsing performance is competitive, and case studies demonstrate real-world applicability.

A2ML is particularly suited for documents where structural correctness is critical: academic papers, technical specifications, standards documents. By moving validation from runtime discovery to compile-time proofs, A2ML reduces errors and increases author confidence.

The A2ML specification, parser implementation, and test suite are available as open source under the PMPL-1.0-or-later license at `https://github.com/hyperpolymath/a2ml`.

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