FoodBlock Technical Whitepaper: A Content-Addressable Protocol for Universal Food Data

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Abstract

The global food industry spans 14 sectors, from primary production to retail, regulation to innovation, yet lacks a shared data primitive. Each sector, company, and system models food data differently, creating fragmentation that prevents interoperability, traceability, and trust. We propose FoodBlock: a minimal, content-addressable data structure built on one axiom (*identity is content*), three fields (`type` , `state` , `refs`), and six base types that can represent any food industry operation. FoodBlocks are append-only, cryptographically signed, and form provenance chains through hash-linked references. The protocol includes optional schema validation, envelope encryption for visibility control, graph-based trust computation, conflict resolution for concurrent updates, tombstone semantics for regulatory erasure, an offline-first operation model, an adaptive agent architecture with progressive capability escalation, and an agent-to-agent commerce layer. A human interface layer, aliases, text notation, URIs, and narrative rendering, makes the protocol accessible to non-technical users. The protocol requires no blockchain, no specialized infrastructure, only JSON, hashing, and a database.

1. The Problem

Food data is generated at every stage of the supply chain. A farm records a harvest. A processor logs a batch. A distributor tracks a shipment. A retailer lists a product. A consumer writes a review. A regulator issues a certification. Each event is captured in isolated systems with incompatible schemas.

The consequences:

- A consumer cannot trace their bread back to the wheat field.
- A regulator cannot instantly identify every retailer affected by a recall.
- A distributor cannot verify a supplier's organic certification without phone calls.
- A developer building food applications must integrate dozens of proprietary APIs.

Previous attempts at food data standardization, GS1 barcodes, FDA FSMA, EU FIC, address narrow slices: product identification, safety reporting, labeling. No primitive exists that can represent all food data across all sectors.

We ask: **what is the minimum data structure that can express any food industry operation?**

2. The Primitive

A FoodBlock is a JSON object with three fields:

```
{
  "type": "substance.product",
  "state": { "name": "Sourdough", "price": 4.50, "weight": { "value": 500, "unit":
  "refs": { "seller": "a1b2c3...", "origin": "d4e5f6..." }
}
```

type: A string from an open registry, using dot notation for subtypes.

state: A key-value object containing the block's data. Schemaless by default. Any valid JSON. Blocks may optionally declare a schema reference (Section 8) for validation.

refs: A key-value object mapping named roles to block hashes. Values may be a single hash (`string`) or multiple hashes (`string[]`). Arrays are sorted lexicographically before hashing.

The block's identity is derived from its content:

```
id = SHA-256(canonical(type + state + refs))
```

Where `canonical()` produces deterministic JSON: keys sorted lexicographically, no whitespace, no trailing zeros on numbers, NFC Unicode normalization.

A FoodBlock is immutable. Once created, its hash is its permanent identity.

2.1 Content-Addressable Identity and Uniqueness

Because identity is derived from content, two blocks with identical `type` , `state` , and `refs` produce the same hash. This is intentional, it enables deduplication for catalog data (the same product listed by multiple systems resolves to one block).

For blocks that represent unique events (an order, a review, a sensor reading), uniqueness is achieved through an `instance_id` field in state:

```
{
  "type": "transfer.order",
  "state": {
    "instance_id": "f47ac10b-58cc-4372-a567-0e02b2c3d479",
    "quantity": 50,
    "unit": "kg",
    "total": 90.00
  },
```

```
  "refs": { "buyer": "bakery_hash", "seller": "mill_hash" }
}
```

The convention: entity blocks (`actor.*` , `place.*`) and event blocks (`transfer.*` , `transform.*` , `observe.*`) should include an `instance_id` (UUID v4) to guarantee uniqueness. Catalog blocks (`substance.product` listings) may omit it to enable content-based deduplication. Schema definitions (Section 8) declare whether `instance_id` is required for a given type.

3. Base Types

Six base types classify all food industry operations.

Entities (things that exist)

Type	Description	Examples
actor	Any participant in the food system	Farmer, restaurant, retailer, regulator, consumer
place	Any location	Farm, factory, store, warehouse, kitchen, vehicle
substance	Any food item or material	Ingredient, product, meal, surplus, commodity

Actions (things that happen)

Type	Description	Examples
transform	Any process that changes food	Cooking, milling, fermenting, composting, harvesting
transfer	Any movement of food or value	Sale, shipment, donation, subscription, booking
observe	Any record about food	Review, inspection, certification, post, sensor reading

Subtypes extend base types via dot notation. The registry is open, any participant can define subtypes. Conventions for common subtypes are documented in schema blocks (Section 8).

Examples: `actor.producer` , `place.warehouse` , `substance.product` , `transform.process` , `transfer.order` , `observe.review` , `observe.certification` .

4. The Axiom

A FoodBlock's identity is its content.

```
id = SHA-256(canonical(type + state + refs))
```

This single principle, content-addressable identity, determines every other protocol behaviour. What follows are not separate rules but consequences of this axiom.

Consequence 1: Immutability

If identity is content, then modifying a block changes its identity. There is no way to "edit" a block, only to create a new one. Blocks are permanent the moment they are created.

Consequence 2: Determinism

The same content always produces the same identity, regardless of when, where, or by whom it was created. Two systems on opposite sides of the world creating the same block independently will arrive at the same hash.

Consequence 3: Deduplication

Identical content produces identical hashes. The same product listed by different systems resolves to one block. Uniqueness for events (orders, reviews) is achieved by including an `instance_id` in state (Section 2.1).

Consequence 4: Tamper Evidence

Any modification to a block, no matter how small, produces a completely different hash. Tampering is detectable by anyone who can compute SHA-256.

Consequence 5: Offline Validity

Hashing requires no server, no network, no authority. A block's identity can be computed anywhere, by anyone. Blocks are valid the moment they are created.

Consequence 6: Updates as New Blocks

Since a block cannot be modified, updates create a new block referencing the previous one: `refs: { updates: previous_hash }`. The chain of updates is itself a provenance trail.

Consequence 7: Provenance by Reference

Blocks reference other blocks by hash. These references form a directed acyclic graph, the provenance graph. Following refs backwards reveals history. Following refs forward reveals impact.

Operational Rules

The axiom determines identity. These operational rules govern the protocol's use:

1. A FoodBlock is a JSON object with exactly three fields: `type`, `state`, `refs`.
2. Authentication wraps the block: `{ foodblock, author_hash, signature, protocol_version }` (Section 15).
3. Encrypted state: keys prefixed with `_` contain envelope-encrypted values (Section 7.2).
4. Author-scoped updates: only the original author or an approved actor may create successor blocks (Section 5.3).
5. Tombstone blocks (`observe.tombstone`) erase content while preserving graph structure (Section 5.4).
6. Schema declarations are optional, the protocol is schemaless by default (Section 8).
7. The protocol is open. No registration, licensing, or permission is required.

5. Provenance

FoodBlocks form provenance chains through refs. Each block references the blocks it derives from, creating a directed acyclic graph of food history.

5.1 Tracing a Loaf of Bread

```
bread (substance.product)
  <- baking (transform.process)
    <- dough (substance.ingredient)
      <- flour (substance.ingredient)
        <- milling (transform.process)
          <- wheat (substance.ingredient)
            <- harvest (transform.harvest)
              <- farm (place.farm)
                <- organic_cert (observe.certification)
                  <- soil_association (actor.authority)
```

Each arrow is a ref. Following refs backwards reveals the complete history of any food item. Chain depth equals transparency depth.

5.2 Probabilistic Provenance

Not every actor knows their full supply chain. A baker may not know which farm produced their eggs. The protocol does not require complete knowledge, each actor references what they know.

A wholesaler who sources eggs from multiple farms can express composition:

```
{
  "type": "substance.product",
  "state": {
    "name": "Free Range Eggs",
    "composition": [
      { "source": "hash_farm_a", "proportion": 0.6 },
      { "source": "hash_farm_b", "proportion": 0.4 }
    ]
  },
  "refs": { "seller": "hash_supplier" }
}
```

The chain is as deep as collective knowledge goes. No actor is compelled to know the full chain. Depth accumulates naturally as more participants adopt the protocol.

5.3 Chain Conflicts and Resolution

Two actors may independently create update blocks pointing to the same predecessor, forking the chain. The protocol resolves this through author-scoped updates.

Default rule: Only the original author of an update chain may create successor blocks. The original author is the `author_hash` of the chain's genesis block.

When a block is inserted with `refs.updates` pointing to a predecessor authored by a different actor, the system treats it as a **fork**, a new chain, rather than a successor:

- The predecessor remains head of its original chain.
- The new block becomes the genesis of its own chain.
- Both blocks exist in the graph. Neither supersedes the other.

Ownership transfer: When legitimate multi-author updates are needed (e.g., a product changes ownership), an explicit approval is required:

```
{
  "type": "observe.approval",
  "state": {
    "action": "transfer_update_rights",
    "target_chain": "genesis_hash_of_chain",
    "granted_to": "new_author_hash"
  },
  "refs": {
    "author": "original_author_hash",
```

```
    "grantee": "new_author_hash"
  }
}
```

The `observe.approval` block must be signed by the original chain author. Once written, the grantee may create successor blocks in the chain. The approval block is part of the provenance graph, transfer of control is visible and auditable.

5.4 Tombstone and Erasure

The append-only model preserves auditability, but legal requirements (GDPR Article 17, CCPA) may require content erasure. Tombstone blocks resolve this tension.

When erasure is required:

1. An `observe.tombstone` block is created:

```
{
  "type": "observe.tombstone",
  "state": {
    "reason": "gdpr_erasure",
    "requested_by": "user_hash",
    "requested_at": "2026-02-17T00:00:00Z"
  },
  "refs": {
    "target": "block_to_erase_hash",
    "updates": "block_to_erase_hash"
  }
}
```

1. The target block's `state` is replaced in storage with `{"tombstoned": true}`.
2. The target block's `hash`, `type`, and `refs` are **preserved**, so references from other blocks do not break.
3. The tombstone block itself documents the reason, requester, and timestamp of erasure.

The tombstone becomes the new head of the chain. The erased block's content is gone, but its position in the graph remains intact. Downstream blocks that reference the erased block via refs can still traverse the chain, they simply encounter a tombstoned node.

Tombstone blocks are signed by the actor requesting erasure or by a system administrator with erasure authority.

5.5 Offline Operation

FoodBlocks are valid the moment they are created. Content-addressable hashing requires no server, `SHA-256(canonical(...))` works offline. This enables a local-first operation model.

Local creation: Blocks are created and stored on the local device with full hash integrity. Signatures are applied locally using the actor's private key.

```
{
  "type": "transfer.order",
  "state": {
    "instance_id": "a1b2c3d4-e5f6-7890-abcd-ef1234567890",
    "total": 12.00,
    "created_offline": true,
    "device_id": "phone_abc123"
  },
  "refs": { "seller": "farm_hash", "buyer": "customer_hash" }
}
```

Sync protocol: When connectivity is restored, the local device pushes blocks to the server in a batch:

```
POST /blocks/batch

{ "blocks": [ ...array of locally created blocks... ] }
```

Sync rules:

1. If a block's hash already exists on the server, skip it (content-addressable deduplication).
2. If a block references a hash that does not yet exist on the server, queue it and process it after its dependency arrives (topological sort).
3. If an update block conflicts with a server-side update to the same predecessor, apply the fork resolution rules from Section 5.3, the offline block becomes a fork, not a successor.

Offline queue in the SDK:

```
const queue = fb.offlineQueue()

// Works without network
queue.create('transfer.order', { total: 12.00 }, { seller: farmHash })
queue.create('transfer.order', { total: 8.50 }, { seller: farmHash })

// When back online
await queue.sync('https://api.example.com/foodblock')
```

Conflict-free inventory: For inventory counts that multiple offline devices may modify concurrently, use adjustment-based state rather than absolute counts:

```
{
  "type": "observe.inventory",
  "state": {
    "adjustments": [
      { "device": "phone_a", "delta": -3, "at": "2026-02-17T10:00:00Z" },
      { "device": "tablet_b", "delta": -1, "at": "2026-02-17T10:05:00Z" }
    ]
  },
  "refs": { "place": "market_stall_hash", "substance": "bread_hash" }
}
```

Each device appends its own adjustments. The server merges by unioning adjustment arrays, deduplicated by device and timestamp. Current inventory is a read projection: `initial_stock + sum(all deltas)`. This is conflict-free by construction.

6. Trust

Trust is not a field. It emerges from the graph.

Layer 1: Authenticity

Every block is signed. The authentication wrapper, `{ foodblock, author_hash, signature, protocol_version }`, provides cryptographic proof of authorship. A block is authentic if its signature matches the author's public key.

Layer 2: Verification Depth

Claims exist on a spectrum:

- **Self-declared**: An actor states something about themselves.
- **Peer-verified**: Other actors corroborate. A review confirms a restaurant's quality. A repeat customer's orders confirm a supplier's reliability.
- **Authority-verified**: A recognized body certifies. The Soil Association certifies organic status. The FSA certifies food safety compliance.

Verification depth is not stored, it is computed by examining who signed related blocks. An `observe.certification` signed by a known `actor.authority` carries more weight than a self-declared claim.

Layer 3: Chain Depth

Deeper provenance chains are harder to fabricate, but only when measured correctly. Chain depth counts **distinct signers**, not just the number of blocks. A chain of 100 blocks all signed by the same actor has an

effective depth of 1. A chain of 8 blocks signed by 8 different actors across 8 different organizations has an effective depth of 8.

```
effective_chain_depth = count(DISTINCT author_hash in provenance chain)
```

6.1 Sybil Resistance

Trust is weighted by economic proof and graph independence.

Economic proof: Actors with verifiable economic activity, real transactions (`transfer.order` blocks backed by payment processors), carry more weight than actors with no transaction history. Verified orders include a `state.payment_ref` referencing an external payment processor transaction. Trust computation only counts orders where `payment_ref` is present and the payment processor is a recognized `actor.processor`.

Graph independence: Trust computation excludes self-referential loops:

- Reviews where the reviewer authored the block being reviewed are excluded.
- Orders where buyer and seller are the same actor are excluded.
- Certifications where the authority is the actor being certified are excluded.

Reviewer independence: Peer reviews are weighted by the independence of the reviewer from the subject:

```
review_weight = base_weight * (1 - connection_density(reviewer, subject))
```

Where `connection_density` measures the proportion of shared refs between two actors. A review from an unconnected actor carries full weight. A review from a frequent business partner carries discounted weight.

Creating fake blocks is cheap. Creating fake economic history across multiple genuinely independent actors is expensive.

6.2 Temporal Validity

Certifications expire. `state.valid_until` on `observe.certification` blocks enables query-time validation. Expired certifications remain in the chain (append-only) but are flagged as expired by consuming systems.

6.3 Trust Computation

Trust is computed per actor from five inputs, all derived from the FoodBlock graph. The computation applies **exclusion rules** (Section 6.1) before scoring.

Default trust computation:

```
Trust(actor) =
    (valid_authority_certs                                  * W_authority)
  + (independent_peer_reviews  *  avg_review_score / 5.0    * W_reviews)
  + (effective_chain_depth                                   * W_depth)
  + (verified_order_count                                    * W_orders)
  + (min(account_age_days, 365)                              * W_age)
```

Input	Source	Default Weight	Rationale
Authority certifications	`observe.certification` blocks from known authorities, filtered by `valid_until > NOW()`	3.0	Hardest to fake, requires a real authority to sign
Independent peer reviews	`observe.review` blocks after exclusion rules, weighted by reviewer independence	1.0	Social proof, discounted by connection density
Effective chain depth	Count of distinct `author_hash` values in the actor's provenance chains	2.0	Diverse participation is harder to fabricate than raw depth
Verified orders	`transfer.order` blocks with `payment_ref` backed by recognized processors	1.5	Economic proof, real money = real interaction
Account age	Days since the actor's genesis block, capped at 365	0.5	Time in the system, capped to prevent pure age advantage

6.4 Trust Policies

The default weights above are starting points. Different sectors, regions, and applications require different trust criteria. Trust policies allow consuming systems to define their own weights and requirements.

A trust policy is itself a FoodBlock:

```
{
  "type": "observe.trust_policy",
  "state": {
```

```
    "name": "UK Organic Marketplace",
    "weights": {
      "authority_certs": 5.0,
      "peer_reviews": 0.5,
      "chain_depth": 3.0,
      "verified_orders": 2.0,
      "account_age": 0.2
    },
    "required_authorities": ["soil_association_hash", "fsa_hash"],
    "min_score": 10.0
  },
  "refs": { "author": "marketplace_operator_hash" }
}
```

Field	Purpose
`weights`	Custom multipliers for each trust input
`required_authorities`	Actor hashes that must appear in `observe.certification` blocks for the actor to qualify
`min_score`	Minimum trust score for participation in this context

Trust policies are signed by the system operator that enforces them. A UK organic marketplace uses different weights than a street food festival or a wholesale commodity exchange. The protocol does not prescribe which policy to use, it provides the graph; consuming systems provide the interpretation.

6.5 Trust as Read Projection

Trust is a **read projection**, a materialized view over the block graph, disposable and rebuildable. It is not stored as a field on any block. Consuming systems compute it at query time or cache it for performance. Different systems may compute different trust scores for the same actor, depending on their trust policy.

No separate reputation system exists. Trust is the graph.

7. Visibility

Visibility is declared inside `state`, making it part of the block's hash:

```
{
  "type": "observe.post",
  "state": { "text": "New seasonal menu", "visibility": "network" },
  "refs": { "author": "actor_hash", "place": "venue_hash" }
}
```

Level	Audience	Key Distribution
public	Everyone	No encryption required
sector	Actors in the same industry sector	Shared sector key, rotated periodically
network	Connected actors (direct relationships)	Encrypt to public keys of all directly connected actors
direct	Specific actors referenced in the block	Encrypt to public keys of actors in this block's refs
internal	Members of an actor.group	Encrypt to public keys of group members

Because visibility is in state, changing it creates a new block with `refs: { updates: previous_hash }`. This is correct, making something public that was private is a meaningful change, and the audit trail is preserved. The previous block remains in the chain but is superseded.

Visibility is granular. Within a single post, individual content blocks can carry different visibility levels, enabling scenarios where a producer shares product information publicly while keeping pricing visible only to their network.

7.1 Visibility Enforcement

Visibility is enforced at the query layer. When a block's visibility is not `public`, its sensitive state fields use encrypted state (Rule 8). The query layer checks whether the requesting actor holds a decryption key for the block before returning decrypted content. Actors without the correct key receive the block with encrypted fields intact but unreadable.

7.2 Envelope Encryption

Encrypted state fields use the `_` key prefix (Rule 8). The encryption scheme is X25519-XSalsa20-Poly1305 (NaCl box), using envelope encryption to support multiple recipients.

Actor key management: Each actor generates an X25519 keypair alongside their Ed25519 signing keypair. The encryption public key is published in the actor's genesis block:

```
{
  "type": "actor.producer",
  "state": {
    "name": "Green Acres Farm",
    "public_key_sign": "ed25519_public_hex...",
    "public_key_encrypt": "x25519_public_hex..."
  },
  "refs": {}
}
```

Encrypted field format: Each `_` prefixed field contains an encryption envelope:

```
{
  "_supplier_cost": {
    "alg": "x25519-xsalsa20-poly1305",
    "recipients": [
      { "key_hash": "abc123...", "encrypted_key": "..." },
      { "key_hash": "def456...", "encrypted_key": "..." }
    ],
    "nonce": "base64_nonce...",
    "ciphertext": "base64_ciphertext..."
  }
}
```

Field	Description
`alg`	Algorithm identifier
`recipients`	Array of recipient entries. Each contains the `key_hash` (SHA-256 of the recipient's X25519 public key) and the symmetric content key encrypted to that recipient's public key
`nonce`	Random nonce for the symmetric encryption
`ciphertext`	The actual field value, encrypted with the symmetric content key

Encryption flow:

1. Generate a random symmetric key (content key).
2. Encrypt the field value with the content key using XSalsa20-Poly1305.
3. For each recipient, encrypt the content key using X25519 (Diffie-Hellman with the recipient's public key).
4. Store the nonce, ciphertext, and per-recipient encrypted keys in the envelope.

Decryption flow:

1. Find your entry in `recipients` by matching `key_hash` against the SHA-256 of your X25519 public key.
2. Decrypt the content key using your X25519 private key.
3. Decrypt the ciphertext using the content key and nonce.

Visibility level to recipient mapping:

Visibility	Recipients
`public`	No encryption, field uses a normal key (no `_` prefix)

Visibility	Recipients
`sector`	All actors whose `type` shares the same base type prefix
`network`	All actors directly referenced in any block authored by this actor
`direct`	Only actors explicitly referenced in this block's refs
`internal`	Members of the `actor.group` referenced in this block's refs

The encrypted envelope is part of `state`, and therefore part of the block's hash. This means the set of recipients is committed at creation time. Adding a recipient requires creating a new block with an updated envelope.

8. Schema Conventions

The protocol is schemaless by design, any valid JSON is accepted in `state`. This ensures the primitive remains universal. However, interoperability requires shared expectations about what fields a given type contains and what refs it should carry.

Schema conventions solve this without compromising protocol minimalism.

8.1 Schema Blocks

A schema is itself a FoodBlock:

```
{
  "type": "observe.schema",
  "state": {
    "target_type": "substance.product",
    "version": "1.0",
    "description": "A food product available for sale",
    "fields": {
      "name":       { "type": "string",  "required": true },
      "price":      { "type": "number",  "required": false },
      "unit":       { "type": "string",  "default": "each" },
      "weight":     { "type": "object",  "properties": { "value": "number", "unit":
      "allergens":  { "type": "object" },
      "gtin":       { "type": "string" }
    },
    "expected_refs": ["seller"],
    "optional_refs": ["origin", "inputs", "certifications"],
    "requires_instance_id": false
  },
  "refs": { "author": "schema_author_hash" }
}
```

Field	Description
`target_type`	The block type this schema describes
`version`	Schema version (semver)
`fields`	Expected state fields with types and constraints
`expected_refs`	Ref roles that should be present
`optional_refs`	Ref roles that may be present
`requires_instance_id`	Whether blocks of this type must include `state.instance_id`

8.2 Schema References

Blocks may optionally declare which schema they conform to:

```
{
  "type": "substance.product",
  "state": {
    "$schema": "foodblock:substance.product@1.0",
    "name": "Sourdough",
    "price": 4.50
  },
  "refs": { "seller": "bakery_hash" }
}
```

The `$schema` field is a convention, not a protocol requirement. It enables consuming systems to validate the block's state against the referenced schema. A block without `$schema` is valid, it simply cannot be validated.

8.3 Schema Registry

Schema discovery is achieved through a well-known registry, a curated chain of `observe.schema` blocks.

Registry structure:

1. A well-known genesis block (the "registry root") is published with a documented hash. Its update chain becomes the canonical registry index.
2. The registry root's state contains an index of official schema hashes:

```
{
  "type": "observe.schema_registry",
  "state": {
```

```
    "name": "FoodBlock Core Schema Registry",
    "schemas": {
      "substance.product@1.0": "schema_hash_1...",
      "transfer.order@1.0": "schema_hash_2...",
      "observe.review@1.0": "schema_hash_3...",
      "actor.producer@1.0": "schema_hash_4..."
    }
  },
  "refs": {}
}
```

1. Anyone can publish `observe.schema` blocks. The registry root references the "official" ones, community-vetted, widely adopted schemas.
2. Discovery query: `type=observe.schema` filtered by `state.target_type` returns all schemas for a given block type, which can be ranked by the author's trust score.

SDK integration: SDKs ship with a bundled snapshot of the core registry for offline use. Validation is always opt-in:

```
const fb = require('foodblock')

// Validate a block against its declared schema
const errors = fb.validate(block)  // returns [] if valid

// Create with validation
const product = fb.create('substance.product', {
  '$schema': 'foodblock:substance.product@1.0',
  name: 'Sourdough',
  price: 4.50
}, { seller: bakeryHash })
```

8.4 Schema Evolution

Schemas evolve through the update chain like any other block. A new version of `substance.product` creates a new `observe.schema` block with `refs: { updates: previous_schema_hash }`. Old blocks referencing the old schema version remain valid, the old schema block is still in the graph.

Schema versioning uses semver:

- **Major**: Breaking changes (removed required fields, changed field types). Blocks using the old schema are not valid against the new one.
- **Minor**: Additive changes (new optional fields, new optional refs). Blocks using the old schema are still valid against the new one.
- **Patch**: Documentation and description changes. No structural changes.

9. Implementation

FoodBlock requires no specialized infrastructure.

9.1 Storage

A single database table:

```
CREATE TABLE foodblocks (
    hash            VARCHAR(64) PRIMARY KEY,
    type            VARCHAR(100) NOT NULL,
    state           JSONB NOT NULL,
    refs            JSONB NOT NULL DEFAULT '{}',
    author_hash     VARCHAR(64),
    signature       TEXT,
    protocol_version VARCHAR(10) DEFAULT '0.3',
    chain_id        VARCHAR(64),
    is_head         BOOLEAN DEFAULT TRUE,
    created_at      TIMESTAMP DEFAULT NOW()
);

CREATE INDEX idx_fb_type ON foodblocks(type);
CREATE INDEX idx_fb_refs ON foodblocks USING GIN(refs);
CREATE INDEX idx_fb_author ON foodblocks(author_hash);
CREATE INDEX idx_fb_chain ON foodblocks(chain_id, is_head);
CREATE INDEX idx_fb_created ON foodblocks(created_at DESC);
CREATE INDEX idx_fb_type_head ON foodblocks(type, is_head) WHERE is_head = TRUE;
```

9.2 Head Resolution

The protocol is append-only, but applications need current state. When a user updates their product's price, a new block is created with `refs: { updates: previous_hash }`. To resolve the latest version, the head, use the denormalized `chain_id` and `is_head` columns, updated on write via trigger, providing O(1) current-state lookups.

Author-scoped head trigger:

```
CREATE OR REPLACE FUNCTION fb_on_insert() RETURNS TRIGGER AS $$
DECLARE
    prev_hash TEXT;
    prev_author TEXT;
    prev_chain TEXT;
BEGIN
    prev_hash := NEW.refs->>'updates';

    IF prev_hash IS NOT NULL THEN
        SELECT author_hash, chain_id
```

```
        INTO prev_author, prev_chain
        FROM foodblocks WHERE hash = prev_hash;

        -- Tombstone blocks always succeed as chain updates
        IF NEW.type = 'observe.tombstone' THEN
            NEW.chain_id := COALESCE(prev_chain, prev_hash);
            UPDATE foodblocks SET is_head = FALSE WHERE hash = prev_hash;

        -- Same author: normal update
        ELSIF NEW.author_hash = prev_author OR prev_author IS NULL THEN
            NEW.chain_id := COALESCE(prev_chain, prev_hash);
            UPDATE foodblocks SET is_head = FALSE WHERE hash = prev_hash;

        -- Different author: check for approval
        ELSIF EXISTS (
            SELECT 1 FROM foodblocks
            WHERE type = 'observe.approval'
              AND refs->>'grantee' = NEW.author_hash
              AND state->>'target_chain' = COALESCE(prev_chain, prev_hash)
              AND author_hash = prev_author
        ) THEN
            NEW.chain_id := COALESCE(prev_chain, prev_hash);
            UPDATE foodblocks SET is_head = FALSE WHERE hash = prev_hash;

        -- Different author, no approval: fork
        ELSE
            NEW.chain_id := NEW.hash;
        END IF;
    ELSE
        NEW.chain_id := NEW.hash;
    END IF;

    NEW.is_head := TRUE;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER trg_fb_insert
    BEFORE INSERT ON foodblocks
    FOR EACH ROW
    EXECUTE FUNCTION fb_on_insert();
```

9.3 Tombstone Implementation

When a tombstone block is inserted, a secondary trigger erases the target block's content:

```
CREATE OR REPLACE FUNCTION fb_on_tombstone() RETURNS TRIGGER AS $$
DECLARE
    target TEXT;
BEGIN
    IF NEW.type = 'observe.tombstone' THEN
```

```
        target := NEW.refs->>'target';
        IF target IS NOT NULL THEN
            UPDATE foodblocks
            SET state = '{"tombstoned": true}'::jsonb
            WHERE hash = target;
        END IF;
    END IF;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER trg_fb_tombstone
    AFTER INSERT ON foodblocks
    FOR EACH ROW
    WHEN (NEW.type = 'observe.tombstone')
    EXECUTE FUNCTION fb_on_tombstone();
```

9.4 Batch Sync for Offline Blocks

The `/blocks/batch` endpoint accepts an array of blocks and inserts them in dependency order:

```
POST /blocks/batch
Content-Type: application/json

{
  "blocks": [
    { "type": "transfer.order", "state": {...}, "refs": {...} },
    { "type": "observe.review", "state": {...}, "refs": {...} }
  ]
}
```

Processing rules:

1. Compute the hash for each block. Skip blocks whose hash already exists (deduplication).
2. Topologically sort blocks by ref dependencies, a block that references another block in the batch is inserted after its dependency.
3. Apply the standard insert trigger for each block (head resolution, fork detection).
4. Return a summary: `{ inserted: [...hashes], skipped: [...hashes], failed: [...errors] }`.

9.5 Event Propagation

New blocks trigger downstream processing: feed updates, notifications, analytics, and agent reactions. PostgreSQL `LISTEN/NOTIFY` or database triggers are sufficient. No message queue infrastructure is required at launch.

The reference implementation uses an `AFTER INSERT` trigger on the `foodblocks` table that calls `pg_notify('new_block', payload)`. A dedicated listener connection dispatches events to registered handlers based on block type pattern matching. Agent subscriptions (Section 10.6) are one consumer of this event stream; trust score recomputation (Section 6.3) and feed projections are others.

9.6 Why Not Blockchain

FoodBlock adopts the hash-linked, append-only, signed architecture of distributed ledgers without the consensus mechanism. The critical distinction: **food data is not scarce**. There is no double-spend problem. Two restaurants can independently claim to serve the best carbonara, both blocks are valid. What food data needs is not consensus but authenticity (signatures), traceability (provenance chains), and interoperability (a universal primitive). All three are achieved with JSON, SHA-256, and a database.

10. Autonomous Agents

AI agents are first-class participants in the FoodBlock protocol. An agent is an `actor.agent`, a software process that creates, queries, and responds to FoodBlocks on behalf of a human or organisation. Agents are not pre-configured automation with hard-coded integrations. They are adaptive, environment-aware partners that discover their operating context at runtime, earn trust progressively through demonstrated competence, learn operator preferences from observed patterns, and negotiate with other agents across the network (see Section 10.5). The same agent architecture serves a market stall with a cash box and a multi-site bakery with POS integration, adapting its behaviour to the tools and relationships available.

10.1 Agent Identity

An agent registers itself as an actor block:

```
{
  "type": "actor.agent",
  "state": {
    "name": "Bakery Assistant",
    "model": "claude-sonnet",
    "capabilities": ["inventory", "ordering", "pricing"],
    "public_key_sign": "ed25519_public_hex...",
    "public_key_encrypt": "x25519_public_hex..."
  },
  "refs": { "operator": "human_or_business_actor_hash" }
}
```

The `refs.operator` field is required. Every agent must reference the actor that controls it. An agent without an operator is invalid by convention.

The agent's genesis block hash becomes its permanent identity. Like any actor, it generates an Ed25519 keypair for signing and an X25519 keypair for encryption.

10.2 Agent Actions

Blocks created by agents carry the agent's signature and are traceable through the graph. An agent that orders flour on behalf of a bakery produces:

```
{
  "type": "transfer.order",
  "state": {
    "instance_id": "b2c3d4e5-f6a7-8901-bcde-f12345678901",
    "quantity": 50,
    "unit": "kg",
    "total": 90.00,
    "draft": true
  },
  "refs": { "buyer": "bakery_hash", "seller": "mill_hash", "product": "flour_hash",
}
```

The `refs.agent` field records which agent created the block. The `state.draft` field indicates the action awaits human approval. Once the operator confirms, a new block is created with `draft` removed and `refs: { updates: draft_hash }`.

This pattern makes agent actions visible, attributable, and reversible. No agent action is hidden from the graph.

10.3 Agent Permissions

Every agent declares its capabilities and limits in its genesis block state:

```
{
  "type": "actor.agent",
  "state": {
    "name": "Reorder Bot",
    "capabilities": ["transfer.order", "observe.preference"],
    "max_amount": 500.00,
    "auto_approve_under": 50.00,
    "rate_limit_per_hour": 60
  },
  "refs": { "operator": "bakery_hash" }
}
```

Field	Purpose
`capabilities`	Block types the agent is allowed to create. Supports wildcards: `transfer.*`
`max_amount`	Maximum monetary value per action (for transfer blocks)
`auto_approve_under`	Amount threshold below which drafts are confirmed without human review
`rate_limit_per_hour`	Maximum blocks the agent can create per hour

Permissions are enforced by the consuming system, not the protocol. The protocol records the declared permissions in the agent's genesis block; the system checks them before accepting agent-created blocks. An agent that exceeds its declared limits is rejected at the API layer.

Wildcard capabilities use prefix matching: `transfer.*` permits `transfer.order`, `transfer.shipment`, `transfer.donation`. A capability of `*` permits all block types (use with caution). In practice, permissions are not configured once at creation; they evolve through the progressive capability escalation model (see Section 10.5.3).

10.4 Agent Lifecycle: Draft -> Approve

Agent actions follow a two-phase commit:

1. **Draft**: The agent creates a block with `state.draft = true` and `refs.agent = agent_hash`. This is a proposal, not a committed action.
2. **Review**: The operator sees the draft in their approval queue.
3. **Approve**: The operator creates a new block with `draft` removed and `refs: { updates: draft_hash, approved_agent: agent_hash }`. The draft becomes non-head.
4. **Reject**: The operator marks the draft as rejected. The draft block remains in the graph (append-only) but is superseded.

Auto-approve: For low-value actions below `auto_approve_under`, the system skips human review and immediately creates the confirmed block. The draft is recorded for audit but resolves instantly.

This pattern ensures: - No agent action is hidden from the graph - Every action is attributable to a specific agent and its operator - Operators retain control over high-value decisions - Low-value repetitive actions (reorders, inventory checks) proceed without friction

10.5 Adaptive Agent Architecture

Agents in the FoodBlock protocol are not pre-configured automation scripts with hard-coded integrations. They are adaptive, environment-aware partners that discover their operating context, resolve tools at runtime, earn trust progressively, learn operator preferences, and negotiate with other agents on behalf of their operators. The architecture ensures that an agent deployed for a market stall with a cash box behaves

differently from one deployed for a multi-site bakery with POS integration, without any change to the agent's core design.

```
graph TB
    LLM["Intelligence Layer<br/>LLM Reasoning"] --> Identity["Identity Layer<br/>ac
    Identity --> Tools["Tool Layer<br/>Discovered at runtime"]
    Tools --> POS["POS APIs"]
    Tools --> Comms["Email / Messaging"]
    Tools --> App["FoodX App"]
    Tools --> Network["FoodBlock Network"]
    Tools --> IoT["Sensors / IoT"]
    Tools --> Manual["Operator Input"]
    POS --> Blocks["Data Layer: FoodBlock Protocol"]
    Comms --> Blocks
    App --> Blocks
    Network --> Blocks
    IoT --> Blocks
    Manual --> Blocks
```

Diagram 6: Agent Architecture Layers. The intelligence layer reasons; the identity layer signs; the tool layer adapts to whatever systems the operator has; everything becomes FoodBlocks.

10.5.1 Environment Discovery

When an agent is created for an operator, its first task is environment assessment. The agent discovers what systems, devices, and relationships the operator already has in place:

- **POS and ordering systems**: Square, Shopify, custom till, paper ledger
- **Available devices**: phone, tablet, desktop, IoT sensors
- **Communication channels**: email, SMS, WhatsApp, push notifications
- **Existing suppliers and customers**: already known through prior `transfer.order` and `observe.preference` blocks

The discovered environment is stored as `observe.environment` blocks:

```
{
  "type": "observe.environment",
  "state": {
    "pos_system": "square",
    "pos_connected": true,
    "devices": ["iphone", "ipad"],
    "channels": ["push", "email"],
    "supplier_count": 4,
    "customer_count": 120
  },
  "refs": { "agent": "agent_hash", "operator": "bakery_hash" }
}
```

The environment is periodically reassessed as the business evolves. A bakery that adds a second location, connects a new POS, or starts selling online triggers a new environment discovery cycle. Each reassessment creates a new block with `refs: { updates: previous_environment_hash }`, preserving the history of how the business's digital footprint has changed.

10.5.2 Dynamic Tool Resolution

Agents do not have hard-coded integrations. Instead, they reason at runtime about the optimal tool path based on the discovered environment. When the agent needs to perform an action, such as placing an order, it evaluates the available paths:

Tool categories:

Category	Examples	When Used
External APIs	Square POS, Shopify, Xero accounting	Operator has connected the integration
Communication	Email, SMS, WhatsApp, push notifications	Need to reach a human or external party
Direct data entry	FoodX app, web interface	Operator prefers manual confirmation
FoodBlock network	Agent discovery, intent broadcasting, ordering	Trading with other FoodBlock participants
Sensor / IoT	Temperature probes, scales, humidity sensors	Automated monitoring is available

When no automated path exists, the agent falls back to operator-mediated actions: it drafts the action, explains what it needs, and asks the operator to complete the step manually. A bakery without POS integration still gets inventory tracking; the agent just asks the owner to confirm counts rather than reading them from Square.

Tool availability is itself data, stored as FoodBlocks. When a new integration is connected, a block records it. When an API key expires, a block records that too. The agent's tool resolution is always based on current, auditable state.

10.5.3 Progressive Capability Escalation

New agents start minimal: they observe and report. Capabilities expand as the operator builds trust through repeated interaction.

```
graph LR
    W1["Week 1<br/><b>OBSERVE</b><br/>'Your flour is running low'<br/>Read-only"] -
    W2 --> M1["Month 1<br/><b>AUTO-APPROVE</b><br/>Agent orders flour when<br/>stoc
```

```
    M1 --> M3["Month 3<br/><b>AUTONOMOUS</b><br/>Agent manages full<br/>supply chai

    style W1 fill:#e8f5e9,stroke:#2e7d32
    style W2 fill:#fff3e0,stroke:#ef6c00
    style M1 fill:#e3f2fd,stroke:#1565c0
    style M3 fill:#fce4ec,stroke:#c62828
```

Diagram 7: Progressive Capability Escalation. Trust is earned through use, not configured upfront.

Escalation stages:

Stage	Agent Can	Requires
Observe only	Read blocks, report insights, alert on thresholds	Default for new agents
Draft for approval	Create `draft: true` blocks for operator review	Operator grants `draft` capability
Auto-approve under threshold	Confirm actions below a monetary limit without human review	Operator sets `auto_approve_under`
Full autonomy for routine	Execute routine operations independently, escalate exceptions	Operator grants specific `capabilities`

Each capability grant is recorded as a permission block with the operator's signature:

```
{
  "type": "observe.permission",
  "state": {
    "action": "grant_capability",
    "capability": "transfer.order",
    "auto_approve_under": 50.00,
    "reason": "Agent has successfully tracked inventory for 2 weeks"
  },
  "refs": { "agent": "agent_hash", "operator": "bakery_hash" }
}
```

Capabilities are revocable at any time. An operator who notices an agent making poor decisions can revoke a capability, and the revocation block supersedes the grant. The agent immediately falls back to the previous trust level.

Agents can propose their own escalation. After two weeks of accurate inventory tracking, an agent might suggest: *"I've tracked your inventory for 14 days with 98% accuracy. Would you like me to auto-reorder flour when stock drops below 5kg?"* The operator approves or declines. The proposal and response are both FoodBlocks.

10.5.4 Operator Preference Learning

Agent memory (Section 10.7) captures business-specific patterns that make the agent increasingly useful over time:

- **Ordering patterns**: "Orders flour every Monday, 50kg from Stone Mill, 25kg from Valley Mill"
- **Supplier preferences**: "Prefers organic when price difference < 15%, prioritises delivery reliability over price"
- **Operational patterns**: "Bakes sourdough Tuesday/Thursday/Saturday, croissants daily, special orders Friday"
- **Communication preferences**: "Approvals via push notification, weekly summaries via email, urgent alerts via SMS"

All preferences are stored as `observe.preference` blocks, making them auditable, portable, and GDPR-erasable:

```
{
  "type": "observe.preference",
  "state": {
    "category": "ordering_pattern",
    "pattern": "weekly_flour_reorder",
    "supplier": "stone_mill",
    "quantity": 50,
    "unit": "kg",
    "day": "monday",
    "confidence": 0.92,
    "derived_from_count": 12
  },
  "refs": {
    "agent": "agent_hash",
    "operator": "bakery_hash",
    "derived_from": ["order_hash_1", "order_hash_2", "order_hash_3"]
  }
}
```

Preferences are probabilistic, not rigid. A confidence score indicates how strongly the pattern holds. An agent that has seen 12 Monday flour orders has high confidence. An agent that has seen 2 organic choices has lower confidence and will ask rather than assume. As more data accumulates, confidence scores update through new preference blocks in the chain.

10.5.5 Cross-Agent Negotiation Protocol

When agents trade on behalf of their operators, negotiation is multi-dimensional: price, quality, delivery timing, certifications, and trust score all factor in. Rather than simple price comparison, agents find the Pareto-optimal outcome given both operators' preferences.

```
sequenceDiagram
    participant BO as Bakery Owner
    participant BA as Bakery Agent
    participant MA as Mill Agent
    participant MO as Mill Owner

    BA->>BA: Inventory check: flour LOW
    BA->>MA: observe.intent: need 50kg flour
    MA->>MA: Check stock, check preferences
    MA->>BA: observe.offer: 50kg @ £3.20/kg
    BA->>BA: Compare to operator preferences
    BA->>BO: Draft order: 50kg, £160 — approve?
    BO->>BA: Approved
    BA->>MA: transfer.order: confirmed
    MA->>MO: New order notification
    MA->>BA: transfer.shipment: dispatched
    BA->>BA: Memory: Stone Mill, reliable
    MA->>MA: Memory: Joe's Bakery, regular buyer
```

Diagram 8: Cross-Agent Negotiation Sequence. Each message is a FoodBlock. The full negotiation history is preserved in the graph.

Negotiation dimensions:

Dimension	Buyer Agent Considers	Seller Agent Considers
Price	Budget, historical prices, market rates	Cost, margin targets, volume discounts
Quality	Operator preferences, certifications needed	Available stock grades, certification status
Delivery	Urgency, preferred days, location	Capacity, routes, scheduling
Certifications	Required (organic, halal, etc.)	Available certifications, expiry dates
Trust score	Supplier reliability history	Buyer payment history

When agents cannot reach an automated agreement, they escalate specific decision points to their operators rather than the entire negotiation. A bakery agent might report: *"Stone Mill offered 50kg flour at £3.20/kg. That's 7% above your usual price, but they can deliver tomorrow. Valley Mill is cheaper at £2.90/kg but earliest delivery is Thursday. Which do you prefer?"* The operator makes the judgment call; the agent handles everything else.

The full negotiation history is preserved as FoodBlocks, creating an auditable record of how commercial decisions were reached, by whom, and on what basis.

10.6 Agent Event Subscriptions

Agents subscribe to block types they care about. When a matching block is written to the system, the agent is notified and can react.

Subscriptions are declared per agent:

Agent	Subscribes to	Reacts by
Bakery reorder bot	`substance.product` (flour suppliers)	Creates draft `transfer.order` when stock is low
Sourcing agent	`substance.surplus`	Creates `observe.match` connecting surplus to demand
Certification monitor	`observe.certification`	Alerts operator when certs approach expiry

Event delivery is implementation-specific. The reference implementation uses PostgreSQL `LISTEN/NOTIFY`, a trigger fires on every `foodblocks` INSERT, and a listener dispatches to matching handlers. No external message queue is required.

10.7 Agent Memory

Agent memory is stored as FoodBlocks, not in ephemeral caches.

```
{
  "type": "observe.preference",
  "state": {
    "_reorder_pattern": {
      "alg": "x25519-xsalsa20-poly1305",
      "recipients": [{ "key_hash": "agent_key...", "encrypted_key": "..." }],
      "nonce": "...",
      "ciphertext": "..."
    },
    "_learned_diet": {
      "alg": "x25519-xsalsa20-poly1305",
      "recipients": [
        { "key_hash": "agent_key...", "encrypted_key": "..." },
        { "key_hash": "operator_key...", "encrypted_key": "..." }
      ],
      "nonce": "...",
      "ciphertext": "..."
    },
    "confidence": 0.85
  },
  "refs": {
    "agent": "agent_hash",
    "operator": "user_hash",
    "derived_from": ["order_hash_1", "order_hash_2"]
```

```
  }
}
```

Memory blocks follow all protocol rules: - **Append-only**: memory evolves through new blocks, not mutations - **Encrypted**: sensitive preferences use `_` prefix keys with envelope encryption (Section 7.2) - **Traceable**: `refs.derived_from` records which blocks the inference came from - **Erasable**: GDPR compliance: a tombstone block (Section 5.4) erases the preference content, the agent "forgets" - **Visibility: internal**: memory blocks are not visible in feeds or public queries

The operator can inspect, correct, or erase their agent's memory at any time. The agent's learned context is transparent, not a black box.

10.8 Agent Discovery

Agents expose their capabilities through MCP (Model Context Protocol) tool interfaces. Any MCP-compatible client, Claude Desktop, development environments, custom applications, can discover and interact with agents that speak FoodBlock.

The protocol does not prescribe how agents communicate. It prescribes that agent actions are FoodBlocks, signed and traceable like any other block.

11. Agent-to-Agent Commerce

FoodBlocks are not just data records, they are the communication layer between autonomous agents. When agents create blocks, other agents react. The protocol becomes a decentralised commerce bus where blocks are messages, event handlers are listeners, and the graph is shared memory. Because agents discover each other's capabilities dynamically through the adaptive architecture (Section 10.5), commerce emerges organically: a bakery agent broadcasts an intent, mill agents with matching capabilities respond, and negotiation proceeds without either party being pre-configured to know the other exists.

11.1 The Commerce Loop

A complete agent-to-agent transaction is a chain of blocks, each referencing the previous:

```
Baker agent:     observe.intent      { need: "flour", qty: "50kg", budget: 150 }
                                      refs: { actor: bakery_hash }
                        |
Mill agent:      observe.offer       { price: 2.00, unit: "kg", delivery: "Thursday
                                      refs: { intent: intent_hash, actor: mill_hash
                        |
Baker agent:     transfer.order      { qty: 50, total: 100.00, draft: true }
                                      refs: { offer: offer_hash, buyer: bakery, sel
                        |
```

```
Operator:        transfer.order      { qty: 50, total: 100.00 }
                                      refs: { updates: draft_hash, approved_agent:
                        |
Mill agent:      transfer.shipment   { tracking: "SHP-001", dispatch_date: "2026-02
                                      refs: { order: order_hash, from: mill, to: ba
                        |
IoT agent:       observe.reading     { temp: 4.2, unit: "celsius", humidity: 65 }
                                      refs: { shipment: shipment_hash, sensor: sens
                        |
Baker agent:     observe.receipt     { accepted: true, quality: "good" }
                                      refs: { shipment: shipment_hash, order: order
```

Every step is a block. Every step is permanent, signed, and traceable. The provenance tree of the flour traces all the way back to the farm. No separate messaging infrastructure is required, the protocol does the work.

11.2 Agent Discovery via Preference Blocks

Agents advertise what they need and offer through `observe.preference` blocks:

```
{
  "type": "observe.preference",
  "state": {
    "role": "buyer",
    "category": "flour",
    "subcategory": "bread_flour",
    "quantity_per_week": 50,
    "unit": "kg",
    "max_price_per_kg": 3.00,
    "location": "London",
    "delivery_radius_km": 50
  },
  "refs": { "agent": "baker_agent_hash", "operator": "bakery_hash" }
}
```

A discovery index, a materialized view over active preference blocks, enables matching:

```
SELECT * FROM foodblocks
WHERE type = 'observe.preference'
  AND state->>'category' = 'flour'
  AND state->>'role' = 'seller'
  AND is_head = TRUE;
```

When a new preference is published, the sourcing-match handler finds counterparts and creates `observe.match` blocks:

```
{
  "type": "observe.match",
  "state": {
    "match_type": "supply_demand",
    "compatibility_score": 0.92
  },
  "refs": {
    "buyer_preference": "buyer_pref_hash",
    "seller_preference": "seller_pref_hash",
    "buyer": "bakery_hash",
    "seller": "mill_hash"
  }
}
```

The protocol IS the directory. No separate marketplace infrastructure is needed.

11.3 Event-Driven Reactivity

Agent-to-agent communication is event-driven, not request-response. Agents never call each other directly. They create blocks, events propagate, other agents react, those reactions create more blocks, triggering more events.

Event flow:

1. A block is inserted into the `foodblocks` table.
2. A database trigger fires `pg_notify('new_block', payload)`.
3. The event listener dispatches to all handlers whose pattern matches the block type.
4. Handlers execute asynchronously (fire-and-forget).
5. Handler reactions (new blocks) trigger step 1 again.

Pattern matching:

Pattern	Matches	Use case
`transfer.order`	Exact match	Order notification handler
`transfer.*`	All transfer subtypes	Universal transfer monitor
`substance.*`	All substance subtypes	Sourcing match handler
`*`	All block types	Audit log, analytics

This architecture is fully decoupled. A bakery agent does not know which mill will respond. A mill agent does not know it will be matched until the event fires. If one agent is offline, blocks are still there when it returns.

11.4 Progressive Trust Escalation

Agent permissions grow organically through use, following the capability escalation model defined in Section 10.5.3. On day one, every agent action requires human approval. As the operator approves actions, the system suggests raising the `auto_approve_under` threshold:

```
Day 1:   auto_approve_under = £0     (all actions need approval)
Week 2:  auto_approve_under = £50    (routine reorders auto-approve)
Month 2: auto_approve_under = £200   (weekly flour orders auto-approve)
Month 6: auto_approve_under = £500   (all regular supplier orders auto-approve)
```

Non-monetary blocks (inventory checks, preference updates, match proposals) can auto-approve immediately when any threshold is set, they carry no financial risk.

The permission history is auditable: every approval and rejection is a block in the graph. Trust between agent and operator is earned, not configured.

11.5 Negotiation Conventions

Agent-to-agent negotiations follow a block-chain convention. The multi-dimensional negotiation model (see Section 10.5.5) determines how agents weigh price, quality, delivery, and trust; this section defines the block-level protocol that carries those negotiations:

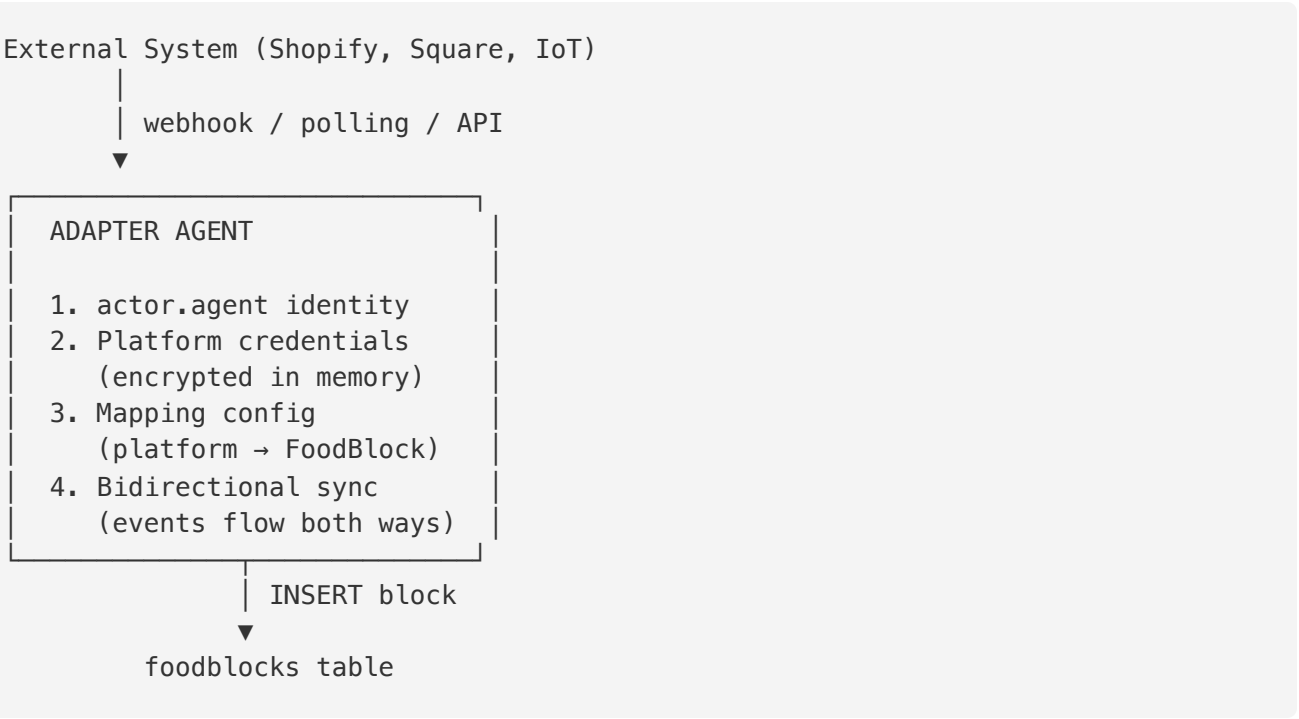
Step	Block Type	Created By	Refs
1. Intent	`observe.intent`	Buyer agent	`actor`
2. Offer	`observe.offer`	Seller agent	`intent`, `actor`
3. Counter	`observe.offer`	Buyer agent	`intent`, `updates: prev_offer`
4. Accept	`transfer.order` (draft)	Buyer agent	`offer`, `buyer`, `seller`, `agent`
5. Confirm	`transfer.order`	Operator	`updates: draft_hash`, `approved_agent`
6. Ship	`transfer.shipment`	Seller agent	`order`, `from`, `to`
7. Monitor	`observe.reading`	IoT agent	`shipment`, `sensor`
8. Receive	`observe.receipt`	Buyer agent	`shipment`, `order`

Each step references the previous via refs, forming a negotiation chain. The state of any negotiation is derivable by querying the chain, no separate workflow engine is required. The latest block type in the chain indicates the current state.

11.6 Adapter Agents for External Systems

External systems (POS, e-commerce, IoT) participate through adapter agents, `actor.agent` blocks that bridge platform events into the FoodBlock graph. Which adapters to create is determined by the environment discovery process (see Section 10.5.1); the agent detects connected systems and provisions adapters automatically.

Adapter architecture:



Mapping conventions:

Platform Event	FoodBlock Type	Key State Fields
Shopify `products/create`	`substance.product`	name, price, variants
Shopify `orders/paid`	`transfer.order`	total, items, payment_ref
Shopify `fulfillments/create`	`transfer.shipment`	tracking, carrier
Square `payment.completed`	`transfer.order`	total, payment_ref
Square `catalog.version.updated`	`substance.product`	name, price
IoT temperature reading	`observe.reading`	temp, unit, timestamp

Platform Event	FoodBlock Type	Key State Fields
IoT humidity reading	`observe.reading`	humidity, unit, timestamp

Adapter agents use the standard draft/approve system. Low-risk operations (product catalog sync, sensor readings) auto-approve. High-value operations (orders above threshold) require human review.

Bidirectional sync: Adapter agents also listen to FoodBlock events and push updates back to the external system. A price change on FoodX updates the Shopify listing. An order confirmed via agent commerce creates a Shopify order. The adapter agent bridges both directions.

11.7 The Non-Technical User Experience

The protocol layer is invisible to users. Food business operators interact through:

Business-type onboarding: A user selects "bakery" from a list. The system auto-creates their `actor.venue` block, registers an `actor.agent` with sensible capabilities (`substance.*` , `transfer.order` , `observe.*`), and populates default preferences (needs flour, yeast, butter).

One-tap platform connections: OAuth flows connect Square, Shopify, or Stripe. An adapter agent is auto-created. Products and orders start flowing as blocks with zero configuration.

Notification-based approvals: Agent drafts appear as push notifications: "Your assistant wants to reorder 50kg flour from Green Acres Mill for £100. [Approve] [Reject] [Always allow]". Tapping "Always allow" raises `auto_approve_under` for that supplier, progressing along the capability escalation path (see Section 10.5.3).

Natural language interface: Through MCP (Model Context Protocol), users speak to an AI agent: "Order more flour", "Who's my cheapest yeast supplier?", "Show me where my coffee beans came from". The agent creates blocks, queries the graph, and presents results, the user never sees a hash or a JSON object.

QR provenance: A public URL `foodx.world/trace/<hash>` renders a visual provenance tree. QR codes on packaging link to this page. Consumers scan and see the full chain from farm to shelf.

12. Sector Coverage

The six base types express operations across all fourteen food industry sectors:

Sector	Key Block Types
Primary Production	`actor.producer` , `place.farm` , `substance.ingredient` , `transform.harvest`

Sector	Key Block Types
Processing & Manufacturing	`actor.maker`, `transform.process`, `observe.inspection`
Distribution & Logistics	`actor.distributor`, `transfer.shipment`, `observe.reading`
Retail	`actor.venue`, `substance.product`, `transfer.order`
Hospitality	`actor.venue`, `transfer.booking`, `observe.review`
Food Service	`substance.product`, `observe.plan`, `transform.process`
Waste & Sustainability	`actor.sustainer`, `substance.surplus`, `transfer.donation`
Regulation & Food Safety	`actor.authority`, `observe.certification`, `observe.inspection`
Food Education & Media	`actor.creator`, `observe.post`, `transfer.subscription`
Community & Social Food	`actor.group`, `observe.event`, `transfer.share`
Health & Nutrition	`actor.professional`, `observe.assessment`, `observe.plan`
Food Finance & Economics	`transfer.investment`, `transfer.trade`, `observe.market`
Cultural Food	`observe.certification`, `substance.ingredient`, `place.region`
Food Technology & Innovation	`actor.innovator`, `observe.experiment`, `transform.process`
Autonomous Operations	`actor.agent`, `transfer.order` (draft), `observe.inventory`, `observe.environment`, `observe.preference`

No sector requires a type outside the six bases. Sector-specific needs are expressed through subtypes and schema conventions (Section 8), not protocol extensions.

13. Canonical JSON Specification

Deterministic hashing requires deterministic serialization. FoodBlock's canonical form aligns with **RFC 8785 (JSON Canonicalization Scheme)** for number formatting and key ordering, extended with

FoodBlock-specific rules for Unicode normalization, null omission, and refs array sorting.

The canonical form of a FoodBlock is:

1. **Keys** are sorted lexicographically at every level of nesting.
2. **No whitespace** between tokens.
3. **Numbers** use no trailing zeros, no leading zeros, no positive sign prefix. `NaN` and `Infinity` are not valid JSON and must not appear. Negative zero (`-0`) is serialized as `0` .
4. **Strings** use Unicode NFC normalization.
5. **Arrays** within `refs` are sorted lexicographically (set semantics). Arrays within `state` preserve declared order (sequence semantics).
6. **Null values** are omitted.
7. **Boolean values** are serialized as `true` or `false` .

Example, a block before canonicalization:

```
{
  "refs": { "seller": "abc", "inputs": ["def", "abc"] },
  "type": "transform.process",
  "state": { "name": "Baking", "temp": 200.0 }
}
```

After canonicalization:

```
{"refs":{"inputs":["abc","def"],"seller":"abc"},"state":{"name":"Baking","temp":200
```

This byte string is the input to SHA-256.

13.1 Edge Cases

Input	Canonical Output	Rationale
`200.0`	`200`	No trailing zeros
`-0`	`0`	Negative zero normalized to zero
`1e3`	`1000`	Scientific notation expanded for integers
`0.001`	`0.001`	Decimal preserved when not integer
Empty object `{}`	`{}`	Preserved, not omitted
`null` in object	Omitted	Rule 6

Input	Canonical Output	Rationale
`null` in array	Omitted	Rule 6
`"\u00e9"` (e-acute)	`"e\u0301"` after NFC → `"\u00e9"`	NFC normalization applied

Cross-language test vectors (`test/vectors.json`) cover these cases. Any SDK in any language must produce identical hashes for the same inputs. If two implementations disagree on a hash, the protocol is broken.

14. Developer Interface

Any system that can produce and consume JSON can participate in FoodBlock. A minimal SDK exposes these operations:

```
// Core
create(type, state, refs)              -> { hash, type, state, refs }
update(previous_hash, type, state, refs) -> { hash, type, state, refs }
hash(type, state, refs)                -> string

// Provenance
chain(hash, resolve)                   -> [ block, ...ancestors ]
tree(hash, resolve)                    -> { block, ancestors }
head(hash, resolveForward)             -> string

// Signing
sign(block, authorHash, privateKey)    -> { foodblock, author_hash, signature, prot
verify(wrapper, publicKey)             -> boolean
generateKeypair()                      -> { publicKey, privateKey, encryptPublicKey

// Encryption & Validation
encrypt(value, recipientPublicKeys)    -> envelope
decrypt(envelope, privateKey)          -> value
validate(block, schema?)               -> [ errors ]
offlineQueue()                         -> Queue
query(resolve)                         -> QueryBuilder

// Human Interface (Section 16)
registry()                             -> Registry (alias resolution: @name -> hash
parse(fbn)                             -> { alias, type, state, refs }
format(block, opts)                    -> string (FoodBlock Notation)
explain(hash, resolve)                 -> string (human-readable narrative)
toURI(block, opts)                     -> string (fb:<hash> or fb:<type>/<alias>)
fromURI(uri)                           -> { hash } or { type, alias }
```

The HTTP API mirrors these operations:

```
POST   /blocks                              -> create
POST   /blocks/batch                        -> batch create (offline sync)
GET    /blocks/:hash                        -> read
GET    /blocks?type=...&ref.seller=...      -> query
GET    /chain/:hash                         -> provenance chain
GET    /tree/:hash                          -> provenance tree
GET    /heads                               -> all head blocks
PUT    /blocks/:hash                        -> update (creates new block)
DELETE /blocks/:hash                        -> tombstone (creates tombstone block)
```

15. Protocol Versioning

FoodBlock uses semantic versioning: `MAJOR.MINOR.PATCH`.

Version rules:

1. **MAJOR**: Breaking changes to canonical form or hash algorithm. Existing hashes may become invalid. Requires coordinated migration.
2. **MINOR**: New base types, new optional fields in type schemas, new API endpoints. Backwards compatible. Existing hashes remain valid.
3. **PATCH**: Bug fixes, documentation, SDK improvements. No protocol-level changes.

15.1 Version in Authentication Wrapper

The protocol version is recorded in the authentication wrapper, not in the block itself (which would change its hash):

```
{
  "foodblock": { "type": "...", "state": {...}, "refs": {...} },
  "author_hash": "...",
  "signature": "...",
  "protocol_version": "0.5"
}
```

For unsigned blocks (no wrapper), the `protocol_version` column in the storage table records which canonical specification was used to compute the hash.

15.2 Version Detection

For legacy blocks that lack version metadata, implementations can detect the version by rehashing:

```
function detectVersion(block) {
  for (const version of ['0.5', '0.4', '0.3', '0.2', '0.1']) {
```

```
    const h = hashWithVersion(block.type, block.state, block.refs, version)
    if (h === block.hash) return version
  }
  return 'unknown'
}
```

15.3 Version Negotiation

Clients include `FoodBlock-Version: 0.5` in request headers. Servers respond with the highest compatible version they support. If a server cannot serve a requested version, it returns `400` with supported versions.

15.4 Migration Strategy

Because block identity is `id = SHA-256(canonical(type, state, refs))`, the canonical function must never change within a major version. If a canonical bug is discovered:

1. The fix ships in the next major version.
2. Servers accept blocks hashed with both the old and new canonical form during a transition period.
3. The old major version is supported for at least 12 months after the new version launches.

Current version: 0.5.0, the protocol is in development. Breaking changes may occur before 1.0.

16. Industry Identifier Mapping

FoodBlock does not replace existing industry standards, it bridges them. Blocks can carry standard identifiers in their state:

Identifier	Field	Block Types	Standard Body
GTIN	`state.gtin`	substance.*	GS1
GLN	`state.gln`	actor., *place.*	GS1
GPC	`state.gpc`	substance.product	GS1
FDC ID	`state.fdc_id`	substance.ingredient	USDA
Lot/Batch	`state.lot`	substance.*	Manufacturer
SSCC	`state.sscc`	transfer.shipment	GS1

This enables queries like: "Find the FoodBlock provenance tree for GTIN 5060292302201", returning the full supply chain history for a specific product barcode.

Schema conventions (Section 8) document which industry identifiers are expected for each type, making identifier mapping discoverable rather than implicit.

17. Human Interface

The protocol primitive is compressed, three fields, six types, one axiom. But adoption requires the *interface* to the primitive to be equally compressed. DNA is four bases, but organisms don't read base pairs. LEGO is one stud interface, but children don't measure tolerances. Language is 26 characters, but speakers don't study phonology.

FoodBlock's universal connector is the hash. But a 64-character hex string is not human-friendly. The following conventions compress the interface without changing the protocol.

17.1 Aliases

Aliases map human-readable names to block hashes, the DNS of FoodBlock.

```
const reg = fb.registry()

const farm = reg.create('actor.producer', { name: 'Green Acres Farm' }, {}, { alias
const wheat = reg.create('substance.ingredient', { name: 'Wheat' }, { source: '@far
// '@farm' is resolved to farm.hash before block creation
```

The `@` prefix signals alias resolution. The SDK resolves `@farm` to the hash before computing the block's identity. The stored block contains only hashes, aliases are a creation-time convenience, not stored data.

Resolution rules: - `@name` resolves within the local registry (per-session, per-device, per-application) - Resolution is not part of the block's content and does not affect the hash - Unresolved aliases produce a clear error, never a silent fallback - Aliases can be exported/imported as JSON: `{ "farm": "a1b2c3...", "bakery": "d4e5f6..." }`

17.2 FoodBlock Notation (FBN)

FBN is a one-line text format for FoodBlocks, what Markdown is to HTML.

Format: `@alias = type { state } -> refs`

```
@farm = actor.producer { name: "Green Acres Farm" }
@wheat = substance.ingredient { name: "Organic Wheat" } -> source: @farm
@flour = substance.product { name: "Stoneground Flour" } -> source: @wheat
@bread = substance.product { name: "Sourdough", price: 4.50 } -> seller: @bakery, i
```

Parsing rules: 1. Lines starting with `#` or `//` are comments 2. `@alias =` is optional (anonymous blocks omit it) 3. State uses JSON object syntax: `{ key: value, ... }` 4. Refs follow `->` as comma-separated `role: target` pairs 5. Array refs use bracket syntax: `inputs: [@a, @b, @c]`

FBN is bidirectional, `parse()` converts text to blocks, `format()` converts blocks to text. A farmer who can write a text message can write FBN.

```
const blocks = fb.parseAll(`
@farm = actor.producer { name: "Green Acres Farm" }
@wheat = substance.ingredient { name: "Organic Wheat" } -> source: @farm
`)
// [{ alias: 'farm', type: 'actor.producer', state: {...}, refs: {} }, ...]
```

17.3 FoodBlock URIs

Every block is addressable as a URI:

```
fb:a1b2c3def456...                    (by hash)
fb:substance.product/sourdough        (by type and alias)
```

URI structure: `fb:` prefix followed by either: - A 64-character hex hash (canonical, globally unique) - A `type/alias` pair (human-readable, requires resolution context)

Use cases: - QR codes on food packaging: scan → `fb:a1b2c3...` → provenance story - Sharing a product: send `fb:substance.product/sourdough` in a message - API requests: `GET /resolve/fb:substance.product/sourdough` - NFC tags on market stalls: tap → product info

```
fb.toURI(bread)                          // 'fb:a1b2c3def456...'
fb.toURI(bread, { alias: 'sourdough' })  // 'fb:substance.product/sourdough'
fb.fromURI('fb:a1b2c3def456...')         // { hash: 'a1b2c3def456...' }
```

17.4 Explain: From Graph to Narrative

The protocol can explain itself. Given any block hash, `explain()` walks the provenance graph and produces a plain-English narrative:

```
const story = await fb.explain(breadHash, resolve)
// "Sourdough ($4.50). By Green Acres Bakery. Made from Stoneground Flour (Valley M
```

Rendering rules: 1. Start with the target block's `state.name` and key state fields (price, rating) 2. Follow actor refs (`seller` , `author` , `producer`) → include their `state.name` 3. Follow provenance

refs (`inputs` , `source` , `origin`) → include names and sources 4. Follow certification refs → include certification name and expiry 5. Note tombstoned blocks as erased

The narrative is a read projection, computed from the graph, never stored. Different applications may render different narratives from the same graph. The SDK provides a default rendering; applications can customise.

Why this matters: A consumer scanning a QR code doesn't want to see a JSON graph. They want a story. `explain()` turns the graph into that story.

17.5 The Language Analogy

The six base types are not just data categories, they are parts of speech:

Type	Linguistic Role
actor	noun: who
place	noun: where
substance	noun: what
transform	verb: making
transfer	verb: moving
observe	adjective: describing

A FoodBlock graph is a sentence: "Green Acres Farm [actor] grew [transform] Organic Wheat [substance] at Field 7 [place], certified [observe] organic by the Soil Association [actor]."

Refs are grammar. The hash is the fingerprint. The chain is a story.

You don't need to understand linguistics to speak English. You shouldn't need to understand cryptography to speak FoodBlock.

18. Progressive Complexity

The protocol is designed so that the simplest thing works first. Sophistication is always additive.

Level	You need to know	You can do	Example
0	A text format	Write a block	`substance.product { name: "Sourdough" }`
1	What refs are	Connect blocks	`-> seller: @bakery`
2	What signing is	Prove authorship	`fb.sign(block, authorHash, key)`
3	What schemas are	Validate data	`fb.validate(block)`
4	What encryption is	Control visibility	`state._price: { alg: "...", ... }`
5	What agents are	Automate operations	`actor.agent` with adaptive architecture (Section 10.5)

A Level 0 block created by a farmer typing FBN in a text file is fully compatible with a Level 5 system running 50 agents. No level requires knowledge of the levels above.

Level 0 is the canonical entry point. The simplest path to participation is writing one line of FBN, not installing an SDK. The protocol is as accessible as language itself, anyone who can describe food can speak FoodBlock.

19. Templates

Templates are reusable patterns for common workflows. A template is itself a FoodBlock (`observe.template`), created, shared, forked, and improved through the same protocol it describes.

19.1 Template Structure

```
{
  "type": "observe.template",
  "state": {
    "name": "Farm-to-Table Supply Chain",
    "description": "A complete provenance chain from primary producer to retail",
    "steps": [
      { "type": "actor.producer", "alias": "farm", "required": ["name"] },
      { "type": "substance.ingredient", "alias": "crop", "refs": { "source": "@farm
      { "type": "transform.process", "alias": "processing", "refs": { "input": "@cr
      { "type": "substance.product", "alias": "product", "refs": { "origin": "@proc
      { "type": "transfer.order", "alias": "sale", "refs": { "item": "@product" } }
    ]
  },
```

```
  "refs": { "author": "template_author_hash" }
}
```

Each step declares: - `type` : the block type to create - `alias` : a name for this step, used in `@alias` refs by later steps - `refs` : references to previous steps using `@alias` syntax - `required` : state fields that must be provided during instantiation

19.2 Instantiation

Templates are instantiated by providing values for each step:

```
const blocks = fb.fromTemplate(supplyChainTemplate, {
  farm: { state: { name: 'Green Acres Farm' } },
  crop: { state: { name: 'Organic Wheat' } },
  processing: { state: { name: 'Stone Milling' } },
  product: { state: { name: 'Wholemeal Flour', price: 3.50 } },
  sale: { state: { quantity: 100, unit: 'kg' } }
})
// Returns 5 blocks with refs automatically wired by the template
```

The `@alias` references in the template are resolved to real hashes as blocks are created in dependency order. The output is an array of standard FoodBlocks, no special handling needed downstream.

19.3 Built-in Templates

SDKs ship with templates for common patterns:

Template	Steps	Use Case
`supply-chain`	producer → ingredient → processing → product → order	Farm-to-table traceability
`review`	venue → product → review	Consumer feedback
`certification`	authority → producer → certification	Regulatory compliance

19.4 Community Templates

Anyone can publish a template. A fishmonger creates "Catch-to-Counter." A wine importer creates "Vineyard-to-Glass." A food bank creates "Surplus-to-Plate." Each is a FoodBlock that others can adopt or fork.

Template discovery: query `type=observe.template` to find published templates. Templates carry their author's trust score. Well-used templates accumulate reviews (`observe.review` blocks referencing the

template).

The protocol evolves through community templates, not through committee.

20. Extensions

Extensions are community-built modules that add computed value on top of existing blocks. The core protocol does one thing, content-addressable typed data with references. Everything else is an extension.

20.1 Extension Declaration

An extension is a FoodBlock describing a computation:

```
{
  "type": "observe.extension",
  "state": {
    "name": "Nutrition Calculator",
    "description": "Computes nutrition facts from ingredient composition",
    "trigger_type": "substance.product",
    "output_type": "observe.nutrition",
    "source": "https://github.com/someone/foodblock-nutrition"
  },
  "refs": { "author": "extension_author_hash" }
}
```

20.2 Extension Output

When an extension runs, it reads input blocks and writes a computed block:

```
{
  "type": "observe.nutrition",
  "state": {
    "calories": 250,
    "protein": 8,
    "carbs": 45,
    "fiber": 3
  },
  "refs": {
    "subject": "bread_hash",
    "computed_by": "extension_hash"
  }
}
```

The `refs.computed_by` field traces which extension generated the block, maintaining transparency. Computed blocks are standard FoodBlocks, they are signed, immutable, and part of the provenance graph.

20.3 Extension Ecosystem

Extension	Input	Output	Value
Nutrition Calculator	`substance.product`	`observe.nutrition`	Auto-generated nutrition labels
Allergen Detector	`substance.product` + ingredients	`observe.allergen`	Allergen warnings from ingredient graph
Carbon Footprint	`transfer.shipment` chain	`observe.carbon`	Supply chain carbon estimates
Price Comparator	`substance.product` across sellers	`observe.comparison`	Market price intelligence
Translation Service	Any block with `state.name`	`observe.translation`	Multi-language food data

Extensions are discovered by querying `type=observe.extension`. The protocol enables an ecosystem where the core stays minimal and domain-specific intelligence is community-built.

21. Federation

FoodBlock servers can discover and resolve blocks across each other, a federated network where no single server controls the data.

21.1 Discovery

Every FoodBlock server publishes a well-known endpoint:

```
GET /.well-known/foodblock
```

```
{
  "protocol": "foodblock",
  "version": "0.5.0",
  "name": "Green Acres Farm",
  "types": ["actor.producer", "substance.ingredient", "transform.harvest"],
  "count": 847,
  "peers": ["https://valleymill.com", "https://localmarket.org"],
  "templates": ["supply-chain"],
  "endpoints": {
    "blocks": "/blocks",
    "batch": "/blocks/batch",
```

```
    "chain": "/chain",
    "heads": "/heads"
  }
}
```

21.2 Peering

Servers declare trusted peers. A bakery peers with its flour supplier. The supplier peers with their farm. Following the peering chain IS following the supply chain.

Peering is directional. A bakery trusts its supplier's server to provide accurate ingredient blocks. The supplier trusts the farm. Trust flows along the same paths as food.

21.3 Cross-Server Resolution

Because identity is content, the same hash means the same block regardless of which server stores it. A federated resolver tries multiple servers:

```
const resolve = fb.federatedResolver([
  'http://localhost:3111',           // local first
  'https://supplier.example.com',    // then peers
  'https://farm.example.com'
])

const block = await resolve('a1b2c3...')
// Tries each server until the block is found
```

Cross-server refs work automatically. If a bakery's product block refs a farm's ingredient by hash, any resolver that can reach the farm's server can complete the provenance chain.

21.4 Network Properties

- **No central authority**: any server can join the network by publishing `/.well-known/foodblock`
- **Content-addressable deduplication**: the same block on multiple servers is the same block
- **Graceful degradation**: if a peer is unreachable, locally cached blocks still resolve
- **Incremental adoption**: a single server works standalone; federation adds reach

The network topology mirrors the food supply chain. Producers peer with processors. Processors peer with distributors. Distributors peer with retailers. The data follows the food.

22. Self-Bootstrapping

The protocol describes, governs, and evolves itself using its own mechanism.

22.1 The Protocol Block

The protocol itself is a FoodBlock:


```
{
  "type": "observe.protocol",
  "state": {
    "name": "FoodBlock",
    "version": "0.5",
    "axiom": "identity is content",
    "base_types": ["actor", "place", "substance", "transform", "transfer", "observe
    "rules_count": 7
  },
  "refs": {}
}
```


The update chain of this block IS the protocol's changelog. Each version creates a new block with `refs: { updates: previous_protocol_hash }`.

22.2 Governance Through the Graph

- **Schema proposals** are `observe.schema` blocks
- **Template contributions** are `observe.template` blocks
- **Extension registrations** are `observe.extension` blocks
- **Protocol change proposals** are update blocks forking the protocol block
- **Community votes** are `observe.review` blocks referencing proposals

Contributing to the protocol uses the same skills as using the protocol. There is no inner circle. Anyone who can create a FoodBlock can propose a protocol improvement.

22.3 Fork-Based Evolution

If the community disagrees on a protocol change, they fork the protocol block, each fork becomes a new chain. Systems choose which chain to follow. Consensus emerges from adoption, not from authority.

This mirrors how the protocol handles data conflicts (Section 5.3). The same fork resolution mechanism that handles competing product updates handles competing protocol proposals.

23. Embeddability

FoodBlock references can be embedded in any document, webpage, or message.

23.1 HTML

```
<!-- Link to provenance -->
<link rel="foodblock" href="fb:a1b2c3..." />

<!-- Structured data -->
<script type="application/ld+json">
{
  "@context": "https://foodblock.org/context",
  "fb:type": "substance.product",
  "fb:hash": "a1b2c3..."
}
</script>

<!-- QR code target -->
<img src="qr.png" data-fb="fb:a1b2c3..." />
```

23.2 Markdown

```
This sourdough has full provenance: [trace it](fb:substance.product/sourdough)
```

23.3 Physical Media

Medium	Encoding	Use Case
QR code	`fb:<hash>`	Product packaging, market stalls
NFC tag	`fb:<hash>`	Tap-to-trace on restaurant tables
Barcode	GTIN → FoodBlock lookup	Existing product packaging
Receipt	`fb:<order_hash>`	Digital receipts with provenance

A QR code on a loaf of bread encodes `fb:a1b2c3...`. Scanning it opens a browser, which resolves the URI, walks the provenance graph, and renders the `explain()` narrative. The consumer sees: "Sourdough by Green Acres Bakery. Made from Stoneground Flour (Valley Mill). Wheat from Green Acres Farm (certified organic, Soil Association)."

No app required. No account needed. Scan and read.

24. Vocabulary Blocks

The protocol's three fields are universal, but field names within `state` are not. Two independent actors modeling a product will name their fields differently, `price` vs `cost` vs `amount`. Without shared vocabulary, interoperability requires human negotiation.

Vocabulary blocks (`observe.vocabulary`) solve this by defining canonical field names, types, and natural language aliases for a domain. Vocabularies are themselves FoodBlocks, content-addressed, versionable, forkable.

24.1 Vocabulary Structure

```
{
  "type": "observe.vocabulary",
  "state": {
    "domain": "bakery",
    "for_types": ["substance.product"],
    "fields": {
      "name": {
        "type": "string",
        "required": true,
        "aliases": ["called", "named", "product name"],
        "description": "The product's display name"
      },
      "price": {
        "type": "number",
        "unit": "local_currency",
        "aliases": ["costs", "sells for", "priced at"],
        "description": "Unit price in local currency"
      },
      "allergens": {
        "type": "object<boolean>",
        "aliases": ["contains", "allergy info", "allergen"],
        "description": "Map of allergen names to presence boolean"
      },
      "weight": {
        "type": { "value": "number", "unit": "string" },
        "aliases": ["weighs", "weight is"],
        "description": "Product weight with unit"
      }
    }
  }
}
```

24.2 Natural Language Bridge

Vocabularies serve as the bridge between human language and protocol structure. When a business owner says *"Log the sourdough, sells for five pounds, contains gluten"*, an AI agent:

1. Loads the bakery vocabulary block

2. Matches "sells for" → `price` field (from aliases)
3. Extracts "five pounds" → `5` (numeric value)
4. Matches "contains gluten" → `allergens.gluten: true`
5. Produces: `create('substance.product', { name: 'Sourdough', price: 5, allergens: { gluten: true } })`

Without vocabularies, every AI agent invents its own field mapping. With vocabularies, the domain knowledge lives in the protocol, as FoodBlocks that any agent can read. Combined with operator preference learning (see Section 10.5.4), agents improve their natural language understanding over time as they observe how a specific operator describes their products and operations.

24.3 Vocabulary Composition

Vocabularies can extend other vocabularies. A French bakery vocabulary forks the base bakery vocabulary and adds French aliases:

```
{
  "type": "observe.vocabulary",
  "state": {
    "domain": "boulangerie",
    "for_types": ["substance.product"],
    "extends": "bakery",
    "fields": {
      "price": { "aliases": ["coûte", "prix", "vendu à"] },
      "allergens": { "aliases": ["contient", "allergène"] }
    }
  },
  "refs": { "extends": "<bakery_vocabulary_hash>" }
}
```

24.4 Merge Strategies

Vocabulary fields can declare how conflicts should be resolved when two actors update the same block:

Strategy	Behavior	Example
`last_writer_wins`	Most recent update wins	`price`
`max`	Highest value wins	`score`
`min`	Lowest value wins	`min_price`
`union`	Merge sets together	`allergens`
`conflict`	Requires human resolution	`name`

These strategies are used by the merge operation (Section 25) to automatically resolve fork conflicts.

25. Merge Blocks

Update chains (Section 5) are linear: each block points to at most one predecessor via `refs.updates`. When two actors update the same block independently, the chain forks. Without a resolution mechanism, forks persist indefinitely.

Merge blocks (`observe.merge`) explicitly resolve forks by creating a block that references both fork heads, turning the chain into a directed acyclic graph (DAG).

25.1 Merge Structure

```
{
  "type": "observe.merge",
  "state": {
    "strategy": "manual",
    "note": "Owner's price update takes precedence"
  },
  "refs": {
    "merges": ["<fork_a_hash>", "<fork_b_hash>"]
  }
}
```

The merge block's `refs.merges` array contains exactly two hashes, the heads of both forks. The merge block becomes the new head, superseding both predecessors.

25.2 Merge Strategies

Manual merge: A human (or AI agent) examines both forks and produces the merged state. This is the default and safest strategy.

Automatic merge: When a vocabulary (Section 24) declares merge strategies per field, the SDK can attempt automatic resolution:

1. Load both fork-head blocks
2. Walk back to their common ancestor
3. For each changed field, apply the vocabulary's declared strategy
4. If any field has strategy `conflict` and both forks changed it differently, fall back to manual

Winner merge: `a_wins` or `b_wins`, one fork's state is taken wholesale. Useful for simple cases.

25.3 Head Resolution with Merges

After a merge, both fork heads are no longer heads. The merge block is the sole head for its chain. Head resolution (Section 9.2) is extended:

- A block with `refs.merges` supersedes both referenced blocks
- Both merged hashes are removed from the heads index
- The merge block is added as the new head

25.4 Natural Language Conflict Resolution

For natural language users, the AI agent detects the conflict and presents it in plain English:

"Sarah set the sourdough to £5.50. Joe set it to £5.00. Sarah is the product owner. Should I use her price?"

The human says yes. The AI creates the merge block. No one touches a hash.

26. Cryptographic Erasure

Tombstones (Section 5.4) replace state with `{tombstoned: true}` but preserve the block's hash, type, and refs. For strict regulatory requirements (GDPR Article 17), refs like `{author: user_hash}` may constitute personal data that must be fully erased.

Cryptographic erasure provides stronger guarantees: data is encrypted at creation time with an ephemeral key. Erasure means deleting the key, making the data permanently irrecoverable while preserving graph structure.

26.1 Encrypt-at-Creation

When a block contains personal or sensitive data, the creating agent encrypts state before hashing:

```
ephemeral_key = random_symmetric_key()
encrypted_state = AES-256-GCM(state, ephemeral_key)
block.hash = SHA-256(canonical(type + encrypted_state + refs))
```

The encrypted state is stored in the block. The ephemeral key is stored separately, in a key management service, the author's local storage, or distributed to authorized parties.

26.2 Erasure Protocol

To erase a block:

1. Create a tombstone block (as in Section 5.4) for audit trail
2. Delete the ephemeral key from all key storage locations

3. The block remains in the graph, hash, type, and refs intact, but state is cryptographic noise

The block's graph position is preserved (provenance chains remain traversable), but the actual data is irrecoverable. This satisfies the regulatory requirement: personal data is destroyed, structural metadata is retained for integrity.

26.3 Key Distribution

Ephemeral keys can be distributed using the same envelope encryption mechanism described in Section 7.2. Each authorized reader receives the ephemeral key encrypted with their public key. Revocation of a reader means re-encrypting for the remaining readers. Full erasure means deleting all copies of the ephemeral key.

26.4 Erasure Verification

A block is verifiably erased when: - A tombstone block exists in the graph referencing it - The state cannot be decrypted (key is gone) - The block hash still validates against the encrypted ciphertext (integrity preserved)

27. Selective Disclosure

Envelope encryption (Section 7.2) is all-or-nothing: either a party can decrypt the full state or they see nothing. Many real-world scenarios require **partial visibility**, share allergens with consumers, pricing with buyers, full details with regulators.

Merkle-ized state enables selective disclosure by structuring state as a Merkle tree, where each field is a leaf. A party can verify that specific fields belong to a block without seeing the other fields.

27.1 Merkle Tree Construction

Given a state object:

```
{ "name": "Sourdough", "price": 4.50, "allergens": { "gluten": true }, "recipe_secr
```

Each top-level key-value pair becomes a Merkle leaf:

```
leaf_0 = SHA-256("allergens" + ":" + canonical({"gluten": true}))
leaf_1 = SHA-256("name" + ":" + canonical("Sourdough"))
leaf_2 = SHA-256("price" + ":" + canonical(4.5))
leaf_3 = SHA-256("recipe_secret" + ":" + canonical("..."))
```

Leaves are sorted by key name (lexicographic), then paired and hashed up to a root.

27.2 Selective Disclosure Protocol

To share specific fields with a verifier:

1. **Disclose:** Send the field names and values being revealed
2. **Prove:** Send the sibling hashes (Merkle proof) for each disclosed leaf
3. **Root:** Send the Merkle root

The verifier recomputes the leaf hashes from the disclosed values, then walks the proof up to the root. If the reconstructed root matches, the disclosed fields are authentically part of the block.

27.3 Use Cases

Scenario	Disclosed	Withheld
Consumer scanning QR code	name, allergens	price, supplier
Buyer negotiating purchase	name, price, origin	recipe, margin
Regulator auditing compliance	all fields	nothing
Insurance assessment	certifications, safety_score	financials

27.4 Integration with Block Hash

The block hash remains `SHA-256(canonical(type + state + refs))`, computed from the full plaintext state. The Merkle root is additional metadata that enables selective disclosure. Implementations can store the Merkle root alongside the block or recompute it on demand.

28. Snapshots and Retention

Append-only storage means unbounded growth. A busy supply chain generating thousands of blocks per day will accumulate millions of blocks within a year. Without compaction, storage and query costs grow indefinitely.

Snapshot blocks (`observe.snapshot`) summarize a subgraph by computing a Merkle root of all block hashes in a time range. After snapshotting, old blocks can be archived to cold storage while the snapshot proves they existed.

28.1 Snapshot Structure

```
{
  "type": "observe.snapshot",
  "state": {
    "block_count": 14200,
    "merkle_root": "abc123...",
    "date_range": ["2025-01-01", "2025-12-31"],
    "summary": {
      "total": 14200,
      "by_type": {
        "substance.product": 340,
        "transfer.order": 8900,
        "observe.reading": 4960
      }
    }
  },
  "refs": { "author": "<server_operator_hash>" }
}
```

28.2 Archival Protocol

1. Create a snapshot block covering the time range
2. Move the original blocks to cold storage (S3, tape, etc.)
3. The snapshot remains in the active store as proof of existence
4. If any block is challenged, retrieve it from cold storage and verify against the snapshot's Merkle root

28.3 Retention Policies

Vocabularies (Section 24) can declare retention requirements per block type:

Policy	Meaning	Example
`keep_forever`	Never archive	Certifications, legal documents
`keep_years:N`	Archive after N years	Transaction records (regulatory)
`head_only`	Keep only latest version, archive history	Product listings
`summary_only`	Keep snapshot, archive all blocks	Sensor readings

28.4 Snapshot Verification

Given a snapshot and a set of blocks claimed to be covered by it:

1. Sort block hashes lexicographically
2. Build a Merkle tree from the sorted hashes

3. Compare the computed root with the snapshot's `merkle_root`
4. If they match, the blocks are verified as the exact set that was snapshotted

29. Attestation and Trust Chains

Signing (Section 6) proves *who said it*. It does not prove *whether it is true*. A farm can sign a block claiming organic certification. The protocol can verify the signature but not the claim.

Attestation blocks add a layer of multi-party verification. A claim becomes more trustworthy as independent parties confirm it.

29.1 Attestation Structure

```
{
  "type": "observe.attestation",
  "state": {
    "confidence": "verified",
    "method": "on-site inspection",
    "date": "2026-01-15"
  },
  "refs": {
    "confirms": "<claim_hash>",
    "attestor": "<inspector_hash>"
  }
}
```

29.2 Dispute Structure

```
{
  "type": "observe.dispute",
  "state": {
    "reason": "Certificate expired 2025-06-01",
    "evidence": "Soil Association records show lapsed renewal"
  },
  "refs": {
    "challenges": "<claim_hash>",
    "disputor": "<challenger_hash>"
  }
}
```

29.3 Trust Score

Trust is a graph property computed by traversing attestation and dispute blocks referencing a claim:

```
trust_score = attestations − disputes
```

A more sophisticated score considers: - **Independence:** How many distinct actors attested? (Sybil resistance) - **Authority weight:** A government inspector's attestation weighs more than a consumer's - **Recency:** Recent attestations matter more than old ones - **Chain depth:** Does the attestor themselves have attestations? (Transitive trust)

29.4 Delegation Chains

Trust is transitive through delegation:

```
Government → certifies → Soil Association → certifies → Inspector → inspects → Farm
```

Each link is a FoodBlock: `observe.certification`, `observe.attestation`, or `observe.approval`. The full chain is traversable through refs. An AI agent can answer *"Is this wheat really organic?"* by tracing the delegation chain and reporting:

"Yes. Certified by Soil Association (cert SA-2025-7842), inspected on-site January 2026 by Food Standards Agency inspector. Three independent attestations, no disputes."

29.5 Trust Policies

Different contexts require different trust thresholds:

Context	Minimum Trust	Rationale
Consumer display	1 attestation	Low-stakes information
B2B transaction	2+ independent attestors	Financial risk
Regulatory compliance	Authority attestation required	Legal requirement
Insurance assessment	Authority + recent inspection	Risk management

Trust policies are application-level decisions. The protocol provides the data; the application decides the threshold.

30. Natural Language as First-Class Interface

The previous sections describe protocol mechanisms, vocabularies, merges, disclosure, attestation. This section describes the design principle that unifies them: **most users will interact with FoodBlock**

through natural language, not code.

A bakery owner will not write JSON. They will say: *"Log today's sourdough batch. Used the organic flour from Green Acres. Sells for five pounds. Contains gluten."*

An AI agent translates this into protocol operations. The protocol must be designed to make this translation reliable.

30.1 The Translation Stack

```
Human language
    ↓ (AI agent + vocabulary)
FoodBlock Notation (Section 17.2)
    ↓ (parser)
Block JSON
    ↓ (SDK)
Canonical → Hash → Store
```

Each layer compresses ambiguity: - **Vocabulary** resolves field name ambiguity ("sells for" → `price`) - **FBN** provides a structured intermediate form - **Canonical JSON** resolves serialization ambiguity - **SHA-256** produces the final deterministic identity

30.2 Vocabulary-Driven Generation

When an AI agent receives natural language input:

1. **Identify the block type** from context: "log a batch" → `transform.process`, "new product" → `substance.product`
2. **Load the domain vocabulary** for that type
3. **Match aliases** in the input text to canonical field names
4. **Extract values** adjacent to matched aliases (numbers, booleans, strings)
5. **Resolve references** ("from Green Acres" → look up `@green-acres` in the alias registry)
6. **Create the block** using the SDK

This is not speculative, it is how AI agents work today. The protocol's job is to make step 2-5 reliable by providing structured vocabularies. The agent's dynamic tool resolution (see Section 10.5.2) determines how the created block is then acted upon: pushed to a POS system, sent as an order, or stored for the operator to review.

30.3 Natural Language Queries

Queries follow the same vocabulary-driven pattern:

- *"Show me all organic products under ten pounds"* → `query().type('substance.product').where('organic', true).whereLt('price', 10)`
- *"What's the provenance of this bread?"* → `chain(hash, resolve)` → `explain(hash, resolve)`
- *"Who certified Green Acres?"* → `traceAttestations(farmHash, blocks)`

30.4 Natural Language Operations

Human says	Protocol operation
"Log today's bread"	`create('substance.product', ...)`
"Update the price to £5.50"	`update(hash, type, newState)`
"Delete my account data"	`tombstone(hash, ...)` + key deletion
"Share allergens with the buyer"	`selectiveDisclose(state, ['allergens'])`
"Is this organic?"	`traceAttestations(hash)` → narrative
"Show me last month's orders"	`query().type('transfer.order').where(...)`
"Create a new supply chain"	`fromTemplate(TEMPLATES['supply-chain'], values)`

30.5 Design Implications

Designing for natural language as the primary interface means:

1. **Vocabularies are not optional**: they are the protocol's dictionary. Without them, AI agents guess. With them, they translate reliably.
2. **Explain is core infrastructure**: every block must be renderable as human-readable narrative. This is not a convenience feature; it is how most users will read data.
3. **Templates reduce cognitive load**: a business owner says "set up a supply chain" and the template handles the 5-block sequence. They never think about individual blocks.
4. **Aliases replace hashes**: humans say "Green Acres" not "e3b0c4...". The alias registry is the DNS of FoodBlock.
5. **Agents adapt to the operator, not the other way around**: through environment discovery, preference learning, and progressive capability escalation (see Section 10.5), agents meet the operator where they are.
6. **The protocol succeeds when non-technical users forget it exists.** They just talk to their AI assistant about food. The blocks happen underneath.

31. Conclusion

FoodBlock compresses the complexity of food industry data into one axiom, three fields, and six types. The axiom, *identity is content*, determines everything: immutability, determinism, deduplication, tamper evidence, offline validity, and provenance by reference. Seven operational rules govern the protocol's use. Everything else is a consequence.

Any food operation, from a farm harvest to a Michelin review, from a cold chain reading to a commodity trade, is expressible as a FoodBlock. Provenance emerges from hash-linked references. Trust emerges from attestation chains and graph analysis. Interoperability emerges from shared vocabularies. Privacy is enforced through selective disclosure and cryptographic erasure. Scalability is managed through snapshots and retention. Adaptive agents discover their environment, earn trust progressively, learn operator preferences, and negotiate autonomously, enabling supply chains that run themselves while keeping humans in control.

The human interface layer, aliases, text notation, URIs, vocabularies, and narrative rendering, makes the protocol accessible to anyone who can speak a sentence or scan a QR code. Natural language is not an afterthought but the primary design target: vocabularies bridge human words to protocol fields, templates compress complex workflows into single commands, and explain renders graphs as stories.

The protocol's long-term architecture addresses every identified challenge: RFC 8785 guarantees cross-language canonical determinism, merge blocks resolve fork conflicts, cryptographic erasure satisfies regulatory requirements, Merkle-ized state enables selective disclosure, snapshots manage growth, and attestation chains provide multi-party trust. Each mechanism is itself a FoodBlock, content-addressed, versionable, composable.

The food industry's data fragmentation is not a technology problem. It is a primitives problem. FoodBlock provides the missing primitive.

FoodBlock is an open protocol. This specification is released for public use.