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> *"When an implementation hits a wall, my instinct is to look for the mathematical structure that removes it — not the hardware that pushes through it."*

This document is organised around **problems and thinking patterns**, not projects. Each section describes a wall I encountered, the question that changed my model of the problem, and the architectural or mathematical key that resolved it. Projects appear as the contexts where these problems arose. The complete archive (22 projects, 2004–2026) is available at flamandzkiartur.com.

The common thread across embedded control, industrial automation, DSP, number theory, and AI architecture is a single reflex: when a standard approach hits a constraint, ask whether the constraint lives in the problem or in the *model* of the problem. In most cases it is in the model — and changing the model removes the constraint entirely rather than pushing harder against it.

6	5	16
preprints on Zenodo	production-validated model replacements	years of R&D practice

Domains: Embedded / AVR / ARM · Control systems · DSP / fixed-point · Number theory · AI architecture · IoT security

Languages & tools: C / ASM · Python · Java · C# · React · FastAPI · Docker · Eagle / Altium · Home Assistant

Problems — Model Replacements

Each card shows one recurring move: locate the assumption that creates the constraint, replace the model, the constraint disappears.

HVAC Control

Project #01 · Boiler Controller

WALL Thermostats regulate temperature *value*. PID requires measuring error against a setpoint. Both need the number. A coal boiler has large thermal inertia — correction always arrives too late.

QUESTION Why does the controller need to know the temperature? The decision is: *increase blower / hold / reduce*. That is a direction, not a value.

KEY Discrete temperature derivative maps to three symbolic states (↑ / → / ↓) acting directly as control commands. No thresholds. No tuning. This principle was later formalised as ARR (see p. 7).

RESULT ±0.1 °C mean deviation over a full heating season on a coal boiler. 5.5 years uninterrupted. ≈11 million measurement records.

Industrial Calibration

Project #03 · LPG Injector Calibrator

WALL Manual calibration: measure needle travel with a caliper, verify on a rotameter. Open loop, operator-dependent. Spread between units: > 0.3 mm. Homologation rejected on repeatability grounds.

QUESTION Why measure geometry? The specification requires that this unit opens at this voltage. That is a *physical event* — directly detectable.

KEY Closed loop on the opening event: stepper advances until sensor fires. Needle travel is exactly what it must be for this unit at this voltage. Caliper and rotameter both eliminated as error sources.

RESULT 0.3 mm → 0.01 mm. Homologation commission requested a live demonstration. Injectors entered the market.

Trigonometry in Embedded Systems

Project #16 · TrueSynth / Prime Engine

WALL All standard methods (CORDIC, Taylor, LUT+interpolation) have non-zero error and timing jitter. Root cause: arbitrary decimal angles miss the LUT grid; interpolation is always required.

QUESTION Why minimise interpolation error? What *causes* it? Angles miss the grid. Eliminate the condition: choose angles that always land exactly on a grid point.

KEY Redefine angle as k/p (p prime). Every such angle lands exactly on the unit circle by algebraic construction. Interpolation becomes unnecessary. Zero error is a property of the construction, not a precision limit.

RESULT ppb = 0 algebraically. 4.7× faster than CMSIS-DSP Q31. Deterministic: 3 cycles/pair at 170 MHz. Zero drift over 10^9 steps.

AI Memory Architecture

Project #19 · FochBot

WALL LLMs are stateless. Every session starts from zero. Each call re-derives context already computed in prior sessions, paying the full inference cost repeatedly.

QUESTION Why reconstruct what is already known? What if the knowledge that emerged from past sessions was stored structurally, and only the relevant fragment loaded?

KEY Two-layer architecture. Layer A: persistent memory map indexed by ARR rhythm-of-access patterns alongside embedding distance. Layer B: autonomous controller that selects context, calls the LLM as a stateless inference component, and evaluates the result without re-deriving anything already known.

RESULT Same move as the boiler controller (2016): eliminate repeated derivation by encoding what matters structurally. Tools and workflows from past sessions reusable without repeated LLM inference cost.

Case Study 1 — Boiler Controller

Project #01 | Nov 2016 – Jul 2022 | 5.5 years in production | AVR Assembly · ATmega328P

The Wall Classical thermostats operate in ON/OFF mode, causing temperature oscillations and delayed response. PID requires computing against a setpoint — and a coal boiler cannot be stopped instantly; combustion continues after airflow closes. Standard control keeps correcting after correction is already too late.

The Question Why does the controller need to know the temperature? The decision it makes is not "is the temperature 65 °C?" The decision is: increase blower output, hold current power, or reduce it. That is a *direction*, not a value.

The Mathematical Key The firmware computes a discrete temperature derivative every 15 seconds and classifies it into three symbolic states:

$\Delta T < 0 \Rightarrow \downarrow$	$\Delta T = 0 \Rightarrow \rightarrow$	$\Delta T > 0 \Rightarrow \uparrow$
Increase blower	Hold power	Reduce blower

The system reacts before the temperature crosses any threshold. A second loop (phase-angle triac control, 10 ms resolution) adjusts combustion air power continuously within each direction state. No tuning. No setpoint arithmetic.

A Detail Worth Noting The LCD backlight blink rate encodes the boiler state: slow blink (750 ms) = temperature rising, fast blink (250 ms) = falling, steady = stable. No extra hardware — the decimal point already existed on the display; its *behaviour* became the status indicator. The same reflex: every resource that already exists can carry information.

ARR Connection This 2016 firmware is the earliest known empirical implementation of what was later formalised as ARR (Relational Rhythm Analyser, 2021+). The code operated on direction, not value, five years before the framework was named. The boiler is the proof of concept for a general decision architecture now applied to AI memory selection in FochBot.

Outcome ±0.1 °C mean deviation over a full heating season on a coal boiler (thermally inert, cannot be stopped on demand). ≈11 million measurement records across 61 monthly databases. Three academic theses based on the system, all graded 5/5. Decommissioned only when the boiler was replaced by a heat pump.

AVR Assembly | Phase-angle control | dT/dt direction control | AVR | ARR precursor (2016)

Case Study 2 — LPG Injector Calibrator

Project #03 | 2010–2011 | Commercial contract | ATmega32 · 2× stepper motor · event sensor

The Wall A manufacturer of LPG injectors calibrated needle stroke manually: measure with a caliper, set with adhesive, verify on a rotameter. Spread between units: > 0.3 mm. The batch submitted for homologation received objections on calibration repeatability. The requirement: a device that eliminated the operator from the loop entirely.

The Question Why measure geometry? The specification does not require a particular needle travel distance. It requires that the injector opens at a particular working voltage. That is a physical event — directly detectable, without measuring any dimension.

The Mathematical Key Close the loop on the physical event, not the geometric measurement.

Sequence: table advances to injector (motor 1, stops on contact sensor) → coil energised at target voltage via PWM → adjustment screw advances step by step (motor 2) → stop on opening event (sensor Punkt_0 fires) → damping steps applied → operator confirms, table retracts.

The needle stroke is exactly what it must be for this specific unit at this voltage — measured under operational conditions, not inferred from geometry. Caliper and rotameter are both eliminated as sources of error.

A Challenging Detail The device was developed remotely: code written abroad, firmware flashed by a collaborating machinist with no electronics background, hardware corrections via annotated photographs. Remote precision: 0.1 mm. After direct on-site observation three failure modes were identified — residual magnetism in the steel stem, incorrect calibration sequence order, and asymmetric stem guidance. After correction: 0.01 mm.

A bistable hydraulic brake (bicycle brake + car-door solenoid + electric door catch, zero current in hold state) locks the adjustment motor during locknut tightening, preventing the head from shifting under torque without keeping any actuator energised.

Outcome Spread reduced from > 0.3 mm to < 0.01 mm. On resubmission the homologation commission raised no calibration objections and **requested a live demonstration of the calibrator**, surprised by the precision achieved. The injectors received homologation and entered the market.

AVR · I2C | Event-based closed loop | Stepper motor control | Bistable hydraulic brake | Remote embedded development

Case Study 3 — TrueSynth / Prime Engine

Project #16 | 2025–2026 | C / ASM · Q31 fixed-point · STM32 Cortex-M0 / M4F

The Wall All standard trigonometric methods for embedded systems — CORDIC, Taylor series, LUT with interpolation — introduce non-zero approximation error and timing jitter. Root cause: arbitrary decimal angles miss the LUT grid, so interpolation is always required. One angle may cost 70 cycles, another 700. Determinism is lost. Minimising the error is the accepted approach; eliminating it is not considered possible.

The Question Why minimise interpolation error? What *causes* it? Angles miss the grid. What if every angle always landed exactly on a grid point? Interpolation would be unnecessary, and both the error and the jitter would disappear from the same decision.

The Mathematical Key Redefine angle as a fraction of a full rotation: $\Delta = k/p$ where p is prime and $k \in \{0, \dots, p-1\}$. Every such angle lands exactly on the unit circle by algebraic construction — not by numerical precision, but because prime-based fractions are exact.

A LUT of 275 entries (primes $p \leq 67$, 2.2 KB Flash, 0 B RAM) covers all such angles. Every lookup is exact: $\cos(2\pi k/p)$ and $\sin(2\pi k/p)$ without interpolation. Mode MI (Modular Iterator): 3 cycles/pair at 170 MHz on Cortex-M4F, fully deterministic, zero drift over 10^9 steps (residual: 2.22×10^{-16} = IEEE 754 machine epsilon).

Method	Cycles	ppb error	Deterministic
TrueSynth Direct LUT (M0)	**482**	**0**	**Yes**
CORDIC (M0)	271	0.9	Yes
LUT 1024 RAM (M0)	635	0.5	Yes
Taylor (M0)	888	98 000	Yes
TrueSynth Mode MI (M4F)	**3/pair**	**0.0**	**Yes**
CMSIS-DSP Q31 (M4F)	14/pair	18 825	No (up to 530)

Outcome ppb = 0 algebraically — the property holds for every prime-grid angle by construction, not as a numerical approximation. 4.7× faster than CMSIS-DSP Q31 with strictly better accuracy. No FPU required; runs on any Cortex-M (M0 through M33). Applications: FOC motor control, DDS synthesis, absolute encoders, robotics.

C / ARM Assembly | Q31 fixed-point | Prime Engine | Relational Trigonometry | STM32 M0 / M4F | FOC · DDS · Encoders

Case Study 4 — FochBot

Project #19 | 2026– | Python · FastAPI · Docker · ChromaDB · ARR

The Wall Large language models are stateless by design. Each API call starts from zero: no memory of prior calls, no accumulated knowledge, no persistent state. Every session re-derives context that was already computed, paying the full token and inference cost repeatedly. RAG retrieves relevant chunks by embedding similarity but does not solve re-derivation: workflows, decisions, and tools built in past sessions are still lost.

The Question Why reconstruct what is already known? The boiler controller (2016) asked the same question about temperature values: why measure the number when only the direction of change matters? FochBot asks: why re-derive context when the structure that emerged from past sessions can be stored and selectively loaded? *Same move, different domain.*

The Architectural Key Two independent layers, each responsible for one concern.

Layer A — Memory Map: Three-level archive: raw sessions, compact index, and knowledge fragments loaded selectively per query. Selection uses ARR rhythm-of-access patterns alongside embedding distance — fragments accessed in a consistent rhythm across sessions are prioritised over fragments that are merely similar but rarely retrieved.

Layer B — Autonomous Controller: Routes queries, evaluates completeness, builds the minimal context package, calls the LLM as a stateless inference component, and assesses the result — without loading full session history. Continuity and memory are the system's responsibility, not the model's.

The Parallel Explicit Boiler controller, 2016: do not store the temperature value — store the direction of change. The value is re-computable; the direction is what drives action. FochBot, 2026: do not re-derive the knowledge that emerged from past sessions — store the compressed structure and load only what the current query needs. Both eliminate a repeated computation by encoding what actually matters at the structural level. ARR — formalised from the boiler pattern in 2021 — now serves as the rhythm-based selection index in Layer A, closing the loop between 2016 and 2024.

Outcome Tools, workflows, and decisions from past sessions reusable in future sessions without repeated LLM inference cost. The system maintains continuity across sessions that the underlying model cannot. V1 (intent classifier) → V2 (microservices, BCRYPT, role-based access) → V3 (two-layer brain architecture). Full technical specification: PDF / DOCX / LaTeX. Active development, 2026-.

Python · FastAPI | ChromaDB | ARR memory selection | Two-layer architecture | Docker | BCRYPT · microservices

Further Cases

LX-DK Password Reset Module

Project #06 · ATtiny · RS232 · 2015–2022

WALL MCU flash was full. No room for a password-reset function inside the existing firmware — a real embedded hardware constraint.
QUESTION Does this function need to live *inside* the firmware?
KEY The RS232 configuration protocol already supported writing to the password memory field from an external device. The reset module was built as a standalone product one architectural layer above. No firmware modification required.
RESULT New commercial product. 500 units sold to the device manufacturer over 7 years, including 3 years after the author's departure. "No room in the code" became a product line and a revenue stream.

Smart Home Security Architecture

Project #22 · Home Assistant · YAML · 2021–

WALL Gate controllers are installed outside, at the gate. The enclosure is not a security barrier. Opening the gate is often a button press on the PCB or a two-pin short — no credential required. An intruder need not attack the software at all.
QUESTION Why harden the authentication layer if it can be bypassed entirely by touching the hardware?
KEY Two independent attack vectors eliminated at the physical level. Power isolation: gate motor has no voltage when closed — no electrical manipulation of the controller can move it regardless of what is shorted or pressed. Night lockdown: all automations disabled after a set hour — a stolen remote or cloned token produces no response.
RESULT Both the direct hardware manipulation vector and the credential theft vector removed by architecture. Five years of daily production operation.

Crossing the GMP Extraction Barrier

Project #21 · Python · GMP · 2025–

WALL `str(mpz)` throws `OverflowError` on numbers exceeding ≈4.3 billion digits. GMP's internal buffer size is typed as `ulong`; the type overflows. A fundamental library limitation.
QUESTION Does a 5.25-billion-digit number need to exist as a single string?
KEY Divide-and-conquer on precomputed decimal powers of 10. Partition into 24 chunks of 150–350 million digits each, all within `ulong` range. Extract in parallel (24 threads, 106 chunks). Never assembled as a whole.
RESULT $2^{17,443,819,648}$ (5 251 112 954 digits) extracted correctly in 32 minutes 53 seconds. Infrastructure required for the Shor simulation and prime research.

ARR — Relational Rhythm Analyser

Flamandzki 2025–

ARR is a decision framework that operates on symbolic direction changes (↑ / → / ↓) rather than numeric values or thresholds. A sliding window of length n classifies the *rhythm* of sequential changes:

$[\uparrow,\uparrow,\uparrow] \Rightarrow$ accelerating rise	$[\uparrow,\downarrow,\uparrow,\downarrow] \Rightarrow$ rhythmic fluctuation
$[\uparrow,\rightarrow,\downarrow] \Rightarrow$ trend decay	$[\uparrow,\uparrow,\downarrow,\downarrow] \Rightarrow$ two-phase cycle
$[\rightarrow,\rightarrow,\rightarrow] \Rightarrow$ stability	$[\downarrow,\downarrow,\downarrow,\downarrow] \Rightarrow$ accelerating fall

Reaction hierarchy: **activate** → **hold** → **weaken** → **sustain** → **ignore** → **reset**. Instability metric: count of direction reversals in the window.

ARR does not know values. ARR does not know thresholds. ARR knows rhythm — and knows when rhythm changes.

Current Research Directions

Mathematical R&D — Relational Number Theory

6 preprints (Zenodo): hyperbolic formulation of Bertrand–Chebyshev theorem, cyclic CRT reinterpretation, $O(N)$ algorithm for numerical semigroup gap posets, prime partition model, rotational primality model, Riemann hypothesis approach. Framework: instead of asking *whether* a structure exists, ask *why* the structure must be exactly that. Tools: Python, Haskell, Lean 4 (partial formalisation).

Prime Sieve with Active-Set Offset

Instead of sieving from 2, compute which primes are *active* (have multiples in the target range) and anchor the sieve at the minimum required starting point. Reduces the working set significantly for large-offset tasks. Applied in the classical Shor simulation and prime-base research. Validated by working tools.

R&D Methodology

This produces a characteristic loop: a practical implementation reveals a pattern (boiler firmware, 2016) → the pattern is formalised into a general framework (ARR, 2025+) → the framework is applied to a new domain (FochBot memory architecture, 2026+). The loop also runs in reverse: a mathematical result (prime-based angle grid) directly informs an engineering decision (TrueSynth LUT structure, 2025).

The result is not interdisciplinary breadth. It is one method applied consistently across domains.

5.5 yr	0.01 mm	ppb = 0	500 u.	5.25 B
Boiler in production	LPG calibrator	TrueSynth (algebraic)	LX-DK units sold	GMP digits extracted