

LYRA-1

Menura novaehollandiae as a Biomimetic Cyborg Platform

Technical Specification: Sensing, Compute, Vocal Synthesis, Actuation, Power and Lifecycle

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Abstract

This document re-describes the Superb Lyrebird as if it were an engineered cyborg robot: eyes as cameras, ears as microphones and an inertial unit, a song-control brain as a sequence-generating compute stack, and a syrinx as a dual-channel acoustic synthesizer. It is a *translation* of established ornithology and neuroscience into computer-science and robotics vocabulary, with quantum-computing notation used where it genuinely clarifies structure. Every line is tagged by evidential status so that documented fact, general avian knowledge, engineering inference and formal analogy are never confused.

1 Scope and evidence conventions

- [D]

Documented for *Menura*: reported specifically for lyrebirds in the cited literature.
- [A]

Avian-general: documented for birds or oscine songbirds, but not measured in lyrebirds specifically.
- [I]

Inference: a logical engineering deduction; not directly measured.
- [F]

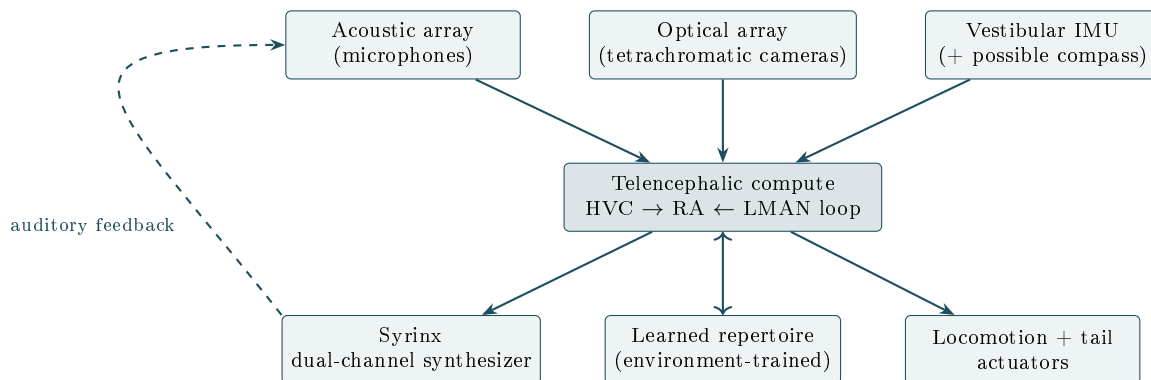
Formal analogy: a modelling language borrowed from CS or quantum computing.

Quantum disclaimer. There is no evidence that the lyrebird brain performs quantum computation. Quantum notation here (Dirac kets, operators, variational loops) is used as a *structural analogy*, tagged [F]. The one place where genuine quantum mechanics is a leading hypothesis in songbirds is magnetoreception (§4.3), and even there it has been studied in migratory species, not lyrebirds.

2 System identification

Parameter	Value	Tag
Unit designation	LYRA-1 (Superb Lyrebird, <i>Menura novaehollandiae</i> Latham, 1801)	[D]
Platform class	Large ground-dwelling oscine passerine; basal oscine with lek-like mating system	[D]
Mass	≈ 1–1.1 kg (large songbird)	[D]
Length, male (incl. tail)	up to ≈ 100 cm; tail 55–70 cm	[D]
Length, female	≈ 76–80 cm; shorter, plainer tail	[D]
Tail array	16 rectrices: 2 lyrates (≈ 60 cm), 2 median ribbon plumes, 12 filamentaries (male); moults annually	[D]
Maturity (tail complete)	Male ≈ 6–9 yr; female ≈ 6–7 yr (sources vary)	[D]
Service life	Up to ≈ 20 yr	[D]
Operating range	South-eastern Australia (rainforest, wet and eucalypt forest); introduced to Tasmania in the 1930s	[D]
Mobility profile	Sedentary; remains within ≈ 10 km radius	[D]
Conservation status	IUCN Least Concern; threats include habitat loss, feral cats, foxes	[D]

3 System architecture



4 Sensor suite

4.1 Optical subsystem (eyes as cameras)

Parameter	Specification	Tag
Spectral range	$\approx 350\text{--}700\text{ nm}$ (human trichromat range is $\approx 400\text{--}700\text{ nm}$)	[A]
Colour channels	Oscine passerines carry the UV-sensitive (UVS) visual system: four single-cone classes (tetrachromacy), plus double cones; coloured oil droplets filter cone input	[A]
Cone peak sensitivities	Shortest class peaks near 360 or 420 nm; other classes cluster near 450–480, 510–540 and 565–620 nm	[A]
Field of view	Laterally placed, relatively large eyes: wide field, limited binocular overlap	[A]
Photopic / scotopic	Cones are $\approx 100\times$ less sensitive than rods; cone mode for day colour, rod mode for dim light	[A]
Application note	UV reflectance is a known signalling channel in birds; lyrebird plumage UV profile not established in the sources consulted	[A]
Eye dimensions, cone ratios, acuity	Not documented for <i>Menura</i> — open item (§10)	—

4.2 Acoustic subsystem (ears as microphones)

Parameter	Specification	Tag
Peak sensitivity band	Avian hearing is most sensitive at $\approx 1\text{--}4\text{ kHz}$	[A]
Ultrasound	No bird species has shown sensitivity above 20 kHz	[A]
Frequency resolution	Roughly one-half to one-third of human resolution within 1–4 kHz	[A]
Transducer	Tympanum, columella (single-bone middle ear), cochlea; small organ but high hair-cell density	[A]
Maintenance	Hair cells damaged by loud noise can be repaired, given recovery time	[A]
Fidelity requirement	Reproducing chainsaws, camera shutters and car alarms implies the front end captures the full spectro-temporal envelope of those sources	[I]
Audiogram for <i>Menura</i>	Not documented — open item	—

4.3 Inertial / orientation subsystem

- **Vestibular IMU.** Semicircular canals give birds a precise sense of balance and orientation; this is the gyroscope-equivalent. [A]

- **Ground-contact balance.** A 1 kg biped that rakes leaf litter, sprints on powerful legs and roosts in trees at night needs continuous attitude control; the vestibular unit is the logical source. [I]
- **Magnetic compass (optional module).** In migratory songbirds the leading hypothesis is a light-dependent radical-pair mechanism in retinal cryptochrome 4; the physics is genuinely quantum (electron spin dynamics). [A] Because lyrebirds are sedentary (≤ 10 km), whether this module is present or used is unknown. [I]

Formal view of the compass [F]: a radical pair is a two-spin system whose singlet–triplet interconversion depends on field orientation, $H = \sum_k \mathbf{I}_k \cdot \mathbf{A}_k \cdot \mathbf{S} + \gamma \mathbf{B} \cdot (\mathbf{S}_1 + \mathbf{S}_2)$; the read-out is a chemical yield, i.e. a measurement of a quantum state, converted to a classical neural signal.

5 Compute stack (the brain)

5.1 Song-control architecture

Vocal-learning birds possess a dedicated telencephalic song system. It has two cooperating pathways. [A]

Module	Function	Tag
HVC	Premotor cortical nucleus; HVC→RA neurons burst sparsely, each at one precise time in the song; the population acts as a time base	[A]
RA	Motor-cortex analogue; converts the sparse time code into muscle commands; projects to brainstem neurons driving the syrinx	[A]
LMAN	Learning pathway: injects quasi-random variability into RA (exploration jitter); essential for song acquisition	[A]
Area X, DLM	Basal-ganglia–thalamic loop (LMAN→Area X→DLM) needed for vocal plasticity; contains song-selective auditory neurons used for feedback	[A]
Brain mass, neuron counts	Not documented for <i>Menura</i> in the sources consulted	—

5.2 Compute model

Fee’s sequence-generation model states that the HVC time code acts on a “muscle map” in RA, so the pattern of HVC→RA synapses is effectively the stored score. [A] In engineering notation [F]:

$$h_i(t) \in \{0, 1\}, \quad \sum_i h_i(t) \ll N \quad (\text{sparse one-hot-like time register}) \quad (1)$$

$$r(t) = \sigma(W h(t) + \epsilon(t)) \quad (\text{RA activity; } \epsilon = \text{LMAN jitter}) \quad (2)$$

$$u(t) = M r(t) \quad (\text{syringeal motor command}) \quad (3)$$

Quantum-notation mapping [F]: label each time-slot by a basis ket $|t_i\rangle$ and each motor pattern by $|m_i\rangle$. The score is the operator

$$\hat{S} = \sum_i |m_i\rangle\langle t_i|, \quad \hat{S} |t_i\rangle = |m_i\rangle. \quad (4)$$

Because HVC neurons are *sparse* and non-overlapping in time, the register behaves like a computational basis rather than a superposition; the analogy is to a classical lookup/sequencer written as a linear map, not to quantum parallelism.

Learning loop as a hybrid variational algorithm [F]: the parameters θ (synaptic weights) are updated against an auditory-feedback loss, while LMAN supplies stochastic exploration, analogous to the classical outer loop of a variational quantum algorithm:

$$\theta_{k+1} = \theta_k - \eta \nabla_{\theta} \mathcal{L}(\theta_k), \quad \mathcal{L}(\theta) = \|\Phi(y_{\theta}) - \Phi(y^*)\|^2, \quad (5)$$

with y_{θ} the synthesized sound, y^* the heard target and Φ a perceptual feature map. Note that acoustic waveforms are classical signals, so mimicry is ordinary copying; the no-cloning theorem does not apply.

6 Vocal and “language” subsystem

6.1 Synthesizer hardware (syrinx)

- Sound arises from vibrating membranes and labia in the syrinx as air passes during expiration, not from vocal cords. Oscine syrinx is tracheobronchial and *bipartite*: two sound sources. [A]
- Lyrebirds are unusual among passerines: **three** pairs of syringeal muscles instead of the usual four. Whether this simplification aids mimicry is unknown. [D]
- Engineering reading: two independently drivable channels $y(t) = y_L(t) + y_R(t)$, formally a tensor-product space $\mathcal{H}_L \otimes \mathcal{H}_R$ of controls [F]. A dual-source design plausibly enables overlapping tones and rapid timbre switching. [I]

6.2 Firmware: repertoire and training data

Parameter	Specification	Tag
Training source	Calls are learned from the local environment, including other lyrebirds	[D]
Mimic share	Roughly 80% of song content is imitation	[D]
Imitated targets	Other birds’ calls, songs, wingbeats and beak claps; dogs; chainsaws; camera shutters; tractors; car alarms; human-made sounds. A recording mimicking an electronic shooting game, workmen and chainsaws was added to Australia’s Sounds of Australia registry in 2013	[D]
Native (non-mimetic) sounds	Twanging, clicking, scissors-grinding, thudding, whirring, “blick”-ing, galloping	[D]
Sequencing	Mimicry appears to come in random order (no fixed grammar reported)	[D]
Female vocal output	Silent during courtship; elaborate displays during foraging (lyrebird-specific song) and nest defence (lyrebird-specific alarm calls), including imitations of predator calls and of other species’ alarm calls and songs	[D]
Courtship I/O	Male performs on a cleared display mound, throwing the tail forward over the body while singing; vocal display immediately precedes copulation	[D]

Interpretation. The system behaves like a generative audio model with (i) a large environment-trained sample library, (ii) a native-sound bank, (iii) a high-fidelity two-channel renderer and (iv) a sequencer without a documented fixed grammar. Whether imitated sounds carry semantic content for conspecifics is not established; the sources describe imitation chiefly as a courtship and territorial signal. [D]/[I]

7 Actuation and chassis

Subsystem	Specification	Tag
Locomotion	Ground-dwelling; long, powerful legs and feet used to run from predators and to travel; rounded wings	[D]
Foraging end-effector	Feet rake leaf litter to expose worms, spiders, insects, occasionally seeds	[D]
Roosting	Night roost in trees	[D]
Display actuator	16-feather tail: lyrates held horizontally at rest, inverted forward over the head during display (silver “umbrella” appearance); shaken in rhythm with song	[D]
Chassis finish	Dark brown / grey body, coppery wings and throat; black legs, feet and bill	[D]

Subsystem	Specification	Tag
Chassis refresh	Annual feather moult; male ornamental tail develops over several years; juveniles lack ornamental feathers	[D]
Joint torques, wing loading, top speed	Not documented in sources consulted	—

8 Power, nest and lifecycle

Parameter	Specification	Tag
Fuel	Omnivore: invertebrates (adult and immature) foraged from ground and under bark; seeds	[D]
Breeding window	Roughly April/June to October (sources differ on start)	[D]
Mating architecture	Dispersed lek: males hold large defended territories with several display mounds; no pair-bonds; one male's territory can overlap up to six female territories	[D]
Brood unit	Female alone builds a dome-shaped nest (sticks, fern, roots, feathers), incubates a single egg (rarely two) and raises the chick	[D]
Fledging	Chick remains in nest ≈ 6 weeks and with the mother up to ≈ 9 months	[D]
Ecosystem function	Raking spreads and thins dry leaf litter; reported to reduce bushfire risk and create refuges that help other species survive fires	[D]
Metabolic rate, power budget	Not documented ; a figure would be an estimate only	—

9 Biology $\leftrightarrow$ CS / robotics / quantum mapping

Biological part	Robotics / CS term	Quantum-notation analogy	Tag
Eye (UVS retina)	4-channel multispectral camera	4-dim colour Hilbert-space read-out	[A][F]
Ear + cochlea	Spectral microphone array	Measurement in frequency basis	[A][F]
Semicircular canals	3-axis gyro / IMU	— (classical)	[A]
Retinal cryptochrome	Magnetic compass sensor	Radical-pair spin system (genuinely quantum)	[A]
HVC	Sparse time-base / sequencer	Basis kets $ t_i\rangle$	[F]
RA	Motor decoder, $r = \sigma(Wh)$	Operator $\hat{S}$	[F]
LMAN / Area X	Exploration noise + critic	Outer loop of hybrid variational scheme	[F]
Syrinx	2-channel physical synthesizer	$\mathcal{H}_L \otimes \mathcal{H}_R$ control space	[F]
Learned repertoire	Environment-trained sample library	Parameterized state family $\{ \psi_\theta\rangle\}$	[F]
Tail	Deployable display array (16 elements)	— (classical)	[D]

10 Open specification gaps

The following values were not found for *Menura* in the sources consulted and are left as open research items rather than invented: eye axial length and cone density; audiogram and vocal bandwidth; brain mass and song-nucleus neuron counts; syringeal muscle force and labial vibration frequencies; wing loading and top running speed; basal metabolic rate; presence and function of a magnetic compass.

Sources consulted (accessed 1 Oct 2026)

- Dalziel & Welbergen (2016), Elaborate mimetic vocal displays by female superb lyrebirds, *Front. Ecol. Evol.* 4:34, doi:10.3389/fevo.2016.00034.
- Superb lyrebird entries: Wikipedia; Museums Victoria Collections; Wildlife Victoria; Animal Diversity Web; BirdForum Opus; Climate Watch; PBS Nature fact sheet; Encyclopedia.com (Lyrebirds, Menuridae).
- Syrinx and mimicry summaries: ZME Science; Why Evolution Is True (2014); biologyinsights.com.
- Song system: Fee et al. (MIT ILP summary); Weizmann lecture notes on birdsong; *PLoS Biol.* commentary on LMAN and AFP; Margoliash et al. (1991), Caltech.
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- Magnetoreception: Wong et al. (2021) *Neuroforum* 27:141; Hore & Mouritsen reviews; Xu et al. (2021) *Nature* on cryptochrome 4.