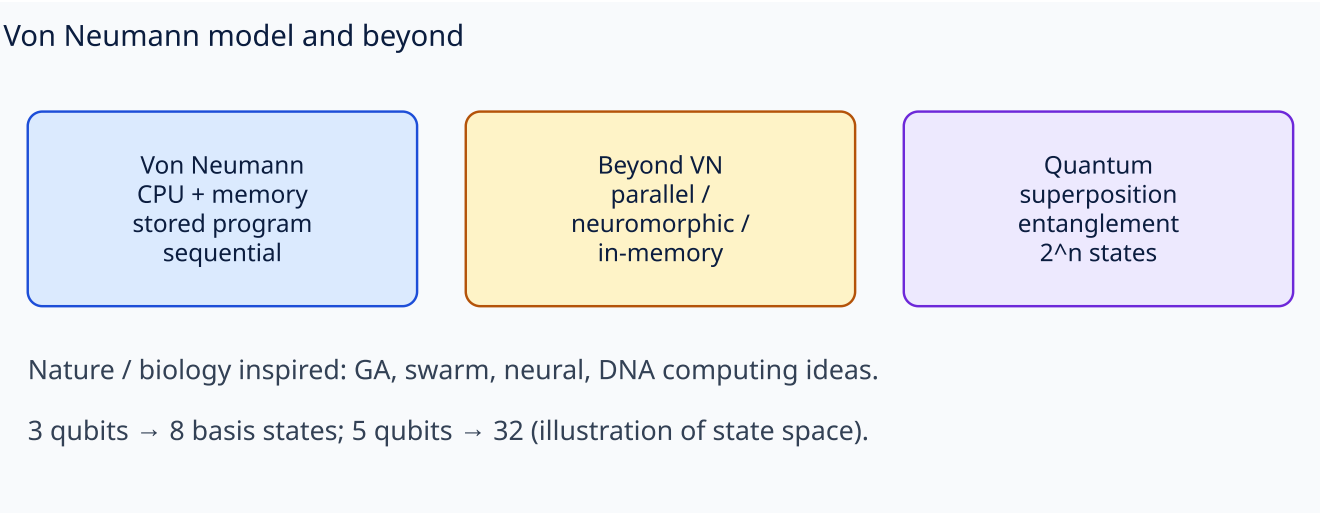
Grade 13 A/L ICT · Lesson 13

13.3 Beyond von Neumann and New Computing Models

Syllabus 13.3. Classical computers follow the **von Neumann** model: a CPU, memory and a stored program, mostly sequential. **Beyond von Neumann** looks at parallel, neuromorphic and in-memory ideas. **Nature-inspired** and **biology-inspired computing** borrow from evolution, swarms and living systems. **Quantum computing** uses quantum bits with superposition (and entanglement in real designs); n qubits span 2^n basis states. Students should know fundamentals and example **applications**, and can discuss wider 2026 directions in Beyond boxes only.

1. Beyond the von Neumann computer

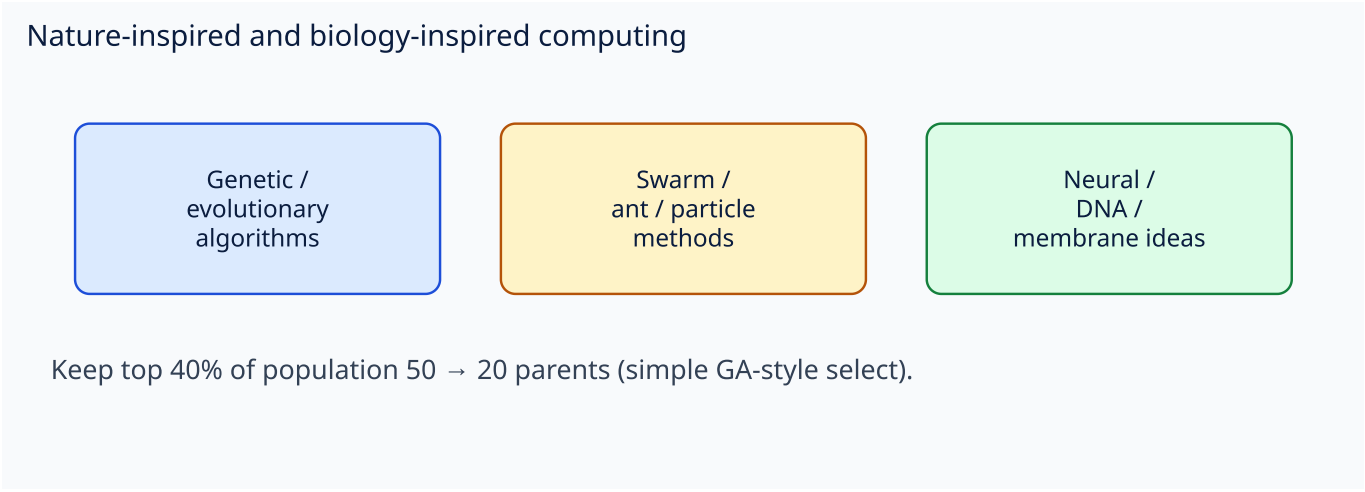


Von Neumann, beyond-VN ideas and quantum state space

- **Von Neumann model** – shared memory, CPU fetches instructions and data; classic bottleneck between CPU and memory.
- **Beyond VN** – more parallelism, specialised accelerators, neuromorphic chips, processing-in-memory, dataflow designs.
- Motivation: speed, energy and problems poorly matched to pure sequential code.

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2. Nature-inspired and biology-inspired computing



Genetic, swarm and neural / DNA-style ideas

- **Nature-inspired** – genetic/evolutionary algorithms, simulated annealing, swarm and ant-colony style search.
- **Biology-inspired** – artificial neural networks, DNA computing concepts, membrane computing ideas.
- Used for optimisation, learning and hard search problems.

> 🧱 **Worked example: Population 50, keep top 40%. How many parents kept?**
> Kept = 50 × 0.4 = **20**.

3. Fundamentals of quantum computing

- **Qubit** – quantum bit that can be in a superposition of |0⟩ and |1⟩.
- n qubits describe a state in a space of 2^n basis states (illustration of capacity).
- **Entanglement** (in real quantum designs) links qubits so they are described together.
- Not a faster laptop for every task – useful for selected algorithms (search, simulation, crypto research).

> 🧱 **Worked example: How many basis states for 3 qubits? For 5 qubits?**
> 2^3 = **8**; 2^5 = **32**.

🐍 Qubit state space size

```
n = 3
states = 2 ** n
print(n, "qubits ->", states, "basis states")
n5 = 5
print(n5, "qubits ->", 2 ** n5, "basis states")
```

▶ Output

```
3 qubits -> 8 basis states
5 qubits -> 32 basis states
```

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4. Applications and outlook

- Quantum research: chemistry simulation, optimisation trials, cryptography impact studies.
- Nature/bio methods: scheduling, routing, pattern learning.
- Beyond-VN chips: AI accelerators in phones and data centres.

🧱 **Worked example: Green ICT example: cut annual use from 12000 kWh to 7800 kWh. Saving and percent?**
Saved = **4200 kWh**; percent = **35.0%**.

🐍 Green ICT energy saving

```
old_kwh, new_kwh = 12000, 7800
saved = old_kwh - new_kwh
pct = round(saved / old_kwh * 100, 1)
print("Saved kWh:", saved)
print("Percent:", pct)
```

▶ Output

```
Saved kWh: 4200
Percent: 35.0
```

💡 2^n grows fast: that is why “a few qubits” can represent a large state space – but building stable qubits is hard.

🚀 **Beyond the syllabus (2026 update)** *Not required for the exam – read for interest.* In 2026: NISQ quantum processors exist but are noisy; GenAI and AR/VR are mainstream; blockchain underpins some ledgers; edge/cloud split work for latency; 5G is widespread and 6G is in research; green ICT tracks data-centre PUE and device energy. Exam questions stay on von Neumann limits, nature/bio inspiration, quantum basics and applications named in the syllabus.

Key Words

Von Neumann architecture – CPU, memory and stored-program sequential model.

Beyond von Neumann – Parallel, neuromorphic, in-memory and related models.

Nature-inspired computing – Algorithms inspired by natural processes such as evolution or swarms.

Biology-inspired computing – Ideas from neural systems, DNA or cells.

Genetic algorithm – Evolutionary search using selection and variation.

Quantum computing – Computing with qubits using quantum effects.

Qubit – Quantum bit with superposition of basis states.

Superposition – Being in a combination of basis states until measured.

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Entanglement – Quantum correlation between qubits.

Neuromorphic – Hardware inspired by neural brain structures.

Parallelism – Doing many operations at once.

Green ICT – Using ICT with lower energy and environmental cost.

Sample Q&A

1. What is the von Neumann model?

> **Answer:** CPU + memory + stored program, typically sequential.

2. Give two beyond-von-Neumann ideas.

> **Answer:** Parallelism / accelerators; neuromorphic or in-memory processing.

3. What is nature-inspired computing?

> **Answer:** Algorithms inspired by nature (evolution, swarms, …).

4. How many basis states do 3 qubits span?

> **Answer:** 8 (2^3).

5. Name one quantum computing application area.

> **Answer:** Chemistry simulation, optimisation trials or crypto research.

6. Population 50 keep 40% → how many?

> **Answer:** 20.

MCQ

1. The von Neumann model mainly uses

A. only abacuses
B. CPU, memory and a stored program
C. only steam looms
D. only vinyl disks
E. only paper ledgers

2. A classic von Neumann concern is

A. lack of chairs
B. too many paperclips
C. the CPU–memory bottleneck
D. ink colour only
E. window size only

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3. Nature-inspired computing includes

A. only handwriting drills
B. only stamp collecting
C. only chalk dust
D. genetic or swarm-style algorithms
E. only candle making

4. Biology-inspired computing includes

A. only knitting patterns
B. neural or DNA-computing ideas
C. only weather vanes
D. only sundials
E. only pottery wheels

5. A qubit differs from a classical bit because it can be in

A. only ink states
B. only steam states
C. only paper states
D. only wooden states
E. a superposition of basis states

6. 3 qubits span

A. 3 states
B. 1 state
C. 6 states
D. 9 states
E. 8 basis states

7. 5 qubits span

A. 32 basis states
B. 64 states
C. 5 states
D. 10 states
E. 16 states

8. Keeping top 40% of population 50 leaves

A. 10
B. 5
C. 20 parents
D. 50
E. 40

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9. Green ICT saving from 12000 to 7800 kWh is

A. 4200 kWh
B. 12000 kWh
C. 100 kWh
D. 1000 kWh
E. 7800 kWh

10. Neuromorphic hardware is inspired by

A. only pencil erasers
B. neural brain structures
C. only bicycle chains
D. only oven timers
E. only door hinges

11. Which term means: “CPU, memory and stored-program sequential model”?

A. Von Neumann architecture
B. Parallelism
C. Quantum computing
D. Nature-inspired computing
E. Superposition

12. Which term means: “Parallel, neuromorphic, in-memory and related models”?

A. Biology-inspired computing
B. Entanglement
C. Qubit
D. Green ICT
E. Beyond von Neumann

13. Which term means: “Algorithms inspired by natural processes such as evolution or swarms”?

A. Genetic algorithm
B. Superposition
C. Neuromorphic
D. Nature-inspired computing
E. Von Neumann architecture

14. Which term means: “Ideas from neural systems, DNA or cells”?

A. Quantum computing
B. Entanglement
C. Parallelism
D. Biology-inspired computing
E. Beyond von Neumann

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15. Which term means: “Evolutionary search using selection and variation”?

A. Neuromorphic
B. Qubit
C. Genetic algorithm
D. Nature-inspired computing
E. Green ICT

16. Which term means: “Computing with qubits using quantum effects”?

A. Quantum computing
B. Superposition
C. Parallelism
D. Biology-inspired computing
E. Von Neumann architecture

17. Which term means: “Quantum bit with superposition of basis states”?

A. Genetic algorithm
B. Beyond von Neumann
C. Qubit
D. Green ICT
E. Entanglement

18. Which term means: “Being in a combination of basis states until measured”?

A. Von Neumann architecture
B. Neuromorphic
C. Quantum computing
D. Superposition
E. Nature-inspired computing

19. Which term means: “Quantum correlation between qubits”?

A. Parallelism
B. Entanglement
C. Biology-inspired computing
D. Qubit
E. Beyond von Neumann

20. Which term means: “Hardware inspired by neural brain structures”?

A. Genetic algorithm
B. Nature-inspired computing
C. Green ICT
D. Superposition
E. Neuromorphic

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Structured Questions

1. Explain the von Neumann model and why designers look beyond it. *(3 marks)*

> CPU/memory/stored program; bottleneck; parallel/neuromorphic/in-memory.

2. Describe nature-inspired and biology-inspired computing with examples. *(3 marks)*

> GA/swarm; neural/DNA; uses.

3. State quantum computing fundamentals: qubit, superposition, 2^n states. *(3 marks)*

> Definitions; 2^n; not universal speedup.

4. Calculate basis states for 3 and 5 qubits; parents kept from 50 at 40%. *(3 marks)*

> 8; 32; 20.

5. Outline applications of new computing models and one green-ICT idea. *(2 marks)*

> Quantum/nature apps; energy saving example.

Summary

- Von Neumann: CPU, memory, stored program.
- Beyond VN: parallel, neuromorphic, in-memory.
- Nature/bio inspired: GA, swarm, neural, DNA ideas.
- Qubits: superposition; n qubits → 2^n states.
- Applications in simulation, optimisation and learning.

MCQ answer key – 13.3

1. **B** – Stored program.
2. **C** – CPU–memory.
3. **D** – Evolution / swarm.
4. **B** – Neural / DNA.
5. **E** – Superposition.
6. **E** – 2^3=8.
7. **A** – 2^5=32.
8. **C** – 50×0.4.
9. **A** – 12000−7800.
10. **B** – Brain-inspired.
11. **A** – Von Neumann architecture – CPU, memory and stored-program sequential model.
12. **E** – Beyond von Neumann – Parallel, neuromorphic, in-memory and related models.
13. **D** – Nature-inspired computing – Algorithms inspired by natural processes such as evolution or swarms.
14. **D** – Biology-inspired computing – Ideas from neural systems, DNA or cells.

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15. **C** – Genetic algorithm – Evolutionary search using selection and variation.
16. **A** – Quantum computing – Computing with qubits using quantum effects.
17. **C** – Qubit – Quantum bit with superposition of basis states.
18. **D** – Superposition – Being in a combination of basis states until measured.
19. **B** – Entanglement – Quantum correlation between qubits.
20. **E** – Neuromorphic – Hardware inspired by neural brain structures.

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