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Generalized Net Model of the Diagnostic Process of Lower Urinary Tract Symptoms in Men

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Introduction

Lower urinary tract symptoms (LUTS) are very common in men, with their prevalence markedly rising with age. The exact frequency depends on how broadly the symptoms are defined.

In the international EPIC population study from 2009 in France, 62.5% of men reported at least one LUTS. The prevalence increased from 51.3% in men under 40 to 80.7% in men over 60. These high figures include even relatively mild or occasional symptoms.

A recent clinical review from 2025 in the US gives a more conservative and clinically meaningful estimate: up to 40% of men older than 50 years have LUTS such as urgency, nocturia, frequency, or weak urinary stream.

Many affected men experience symptoms from more than one LUTS category, and several underlying mechanisms may coexist.

Introduction

Lower Urinary Tract Symptoms

Storage symptoms
- Increased frequency
- Urgency and nocturia
- Urinary incontinence

Voiding symptoms
- Hesitancy and straining
- Slow or intermittent stream
- Terminal dribbling

Post-micturition symptoms
- Incomplete emptying
- Post-micturition dribble

Possible disorder mechanisms

- Prostate-related or other bladder outlet obstruction
- Bladder dysfunction (detrusor over-/underactivity)
- Infection or inflammation
- Structural or urothelial pathology
- Neurological or systemic dysfunction
- Malignancy

The severity of symptoms does not reliably identify their cause.

Several mechanisms may coexist in the same patient.

The diagnostic process cannot be represented as a single fixed sequence of examinations.

Introduction

LUTS diagnosis specifics

1. **Information is acquired in parallel**

   History, symptom scores, physical examination, urinalysis, uroflowmetry with PVR

2. **Further tests are selected conditionally**

   PSA/risk assessment, microbiology, imaging, cystoscopy, urodynamics or neurological assessment

3. **Results have different information states**

   Negative ≠ invalid ≠ unavailable ≠ pending ≠ not indicated

4. **Several hypotheses may remain active**

   Mixed pathology is clinically plausible

5. **Reassessment may be necessary**

   Incomplete, inconsistent, technically inadequate or outdated information

Introduction

Connection to previous research

Earlier approach	Principal focus
Anatomical and physiological GN [9]	Organs and physiological flows
Criterion-based LUTS GN model [10]	Evaluation using selected clinical criteria
Present model	Organisation and integration of the patient-specific diagnostic process

The present paper takes a complementary, process-oriented approach.

Its primary question is not simply how selected criteria are evaluated, but:

How is heterogeneous clinical information generated, validated, combined, and interpreted throughout a patient-specific diagnostic episode?

[9] Lubich, M., Atanassov, K.T., Vassilev, P., Atanassova, V., Slavov, C., Popov, E., Todorova, L.: Generalized net modelling of the male urinary system with prostate-related outflow obstruction. Frontiers in Network Physiology, 6, 1888801 (2026). 10.3389/fnetp.2026.1888801

[10] Mirinchev, N., Sotirova, E., Cholakova, Z., Mirincheva, Z., Atanassov, K.T.: A generalized net model of the process of evaluation the symptoms of the lower urinary tract. In: Atanassov, K.T., Atanassova, V., Kacprzyk, J., et al. (eds.) Uncertainty and Imprecision in Decision Making and Decision Support: New Advances, Challenges, and Perspectives. Lecture Notes in Networks and Systems, vol. 1857, pp. 365–372. Springer, Cham (2026). 10.1007/978-3-032-22232-9_34

Guiding principles in building the GN model

Patient continuity — **Token identity and accumulated token characteristics**

- Preserve patient and episode identity
- Accumulate information over time

Flexible diagnostic flow — **Parallel token movement and predicate-controlled transitions**

- Parallel activities
- Conditionally activated investigations

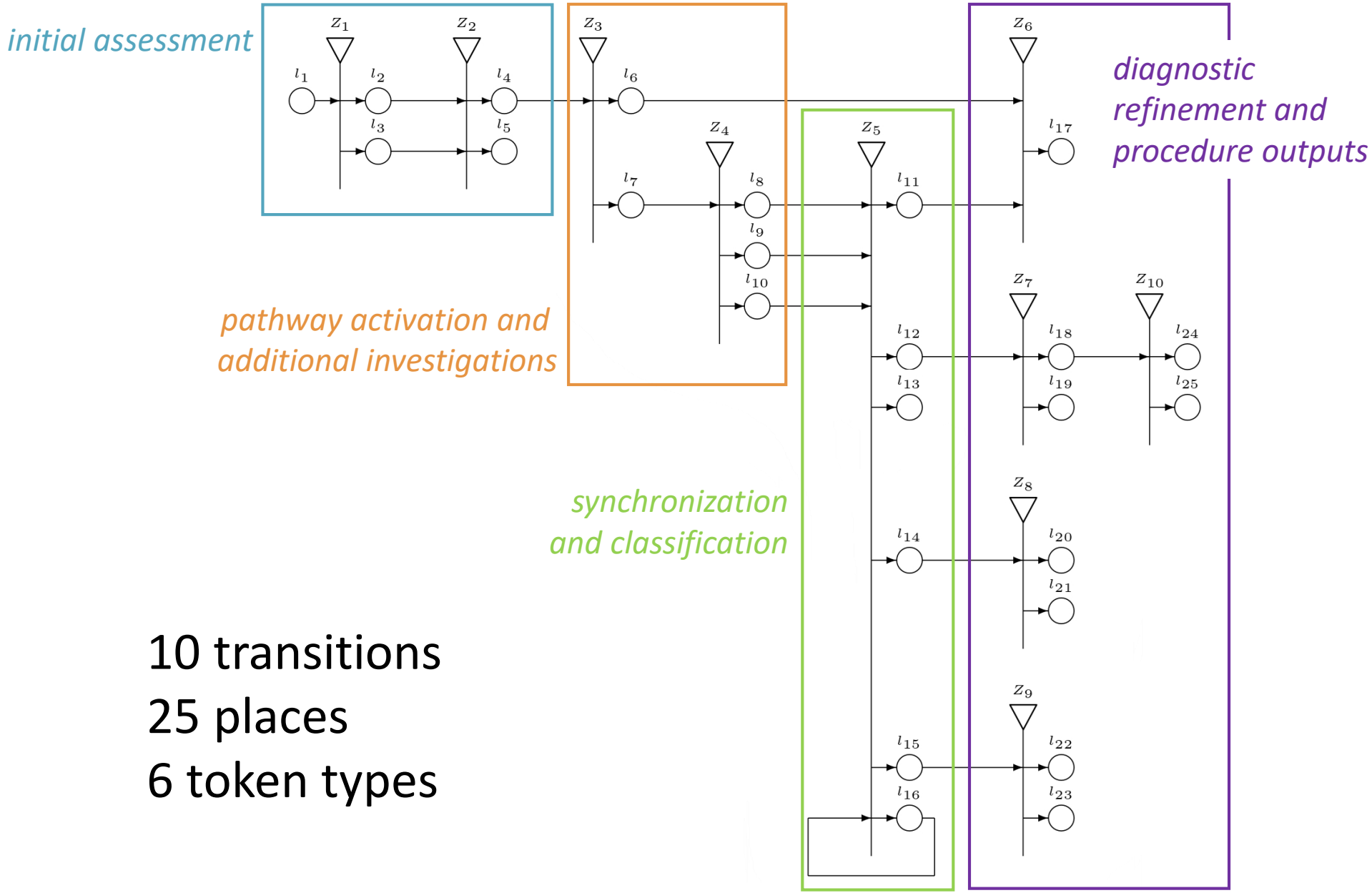
Clinical plurality — **Non-exclusive conditional predicates and token splitting**

- Non-exclusive hypotheses
- Mixed pathophysiology

Uncertainty and reassessment — **Token states and feedback arcs**

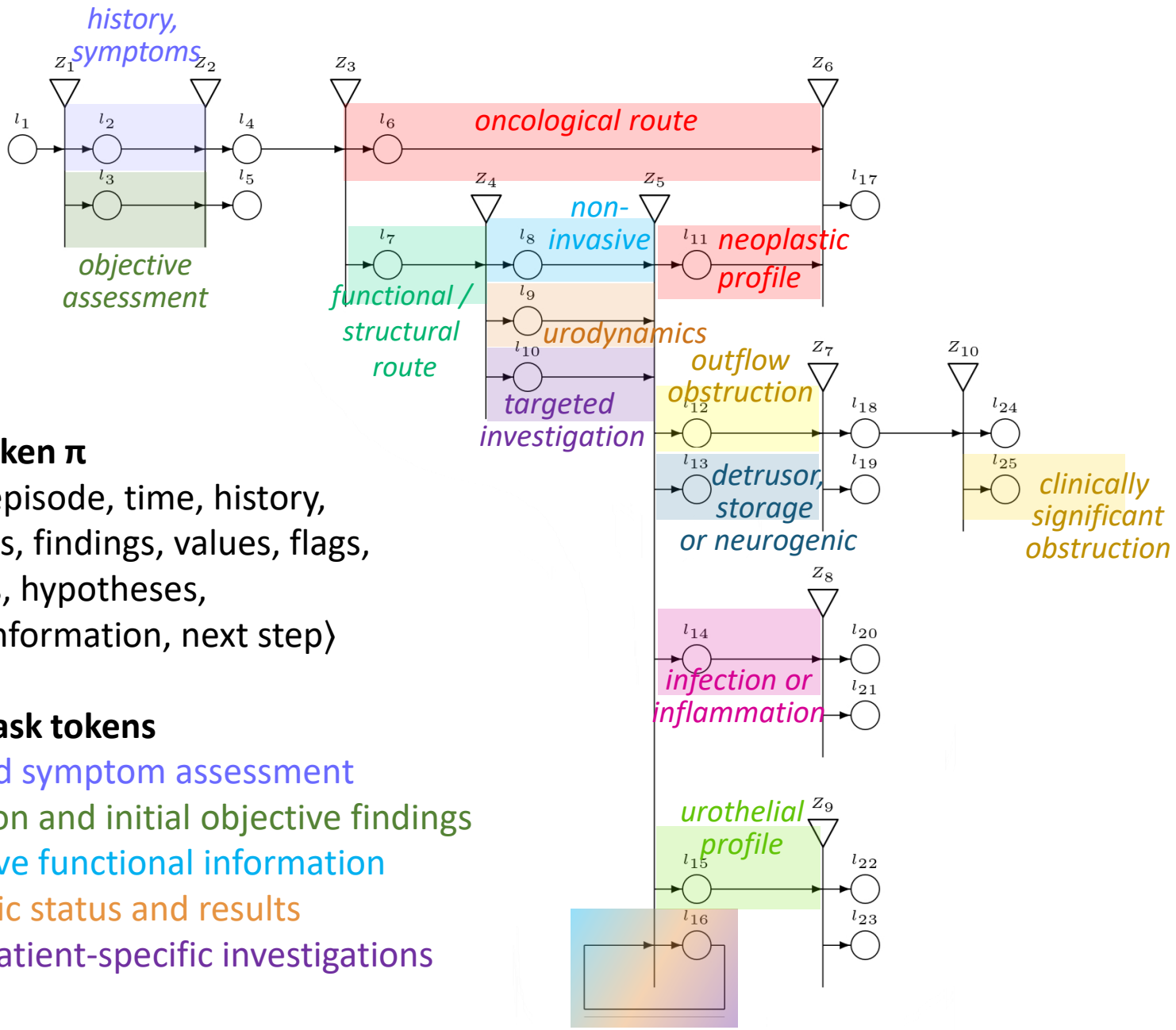
- Distinguish unresolved information states
- Return for further investigation when necessary

Generalized Net model architecture



10 transitions
25 places
6 token types

Generalized Net model architecture



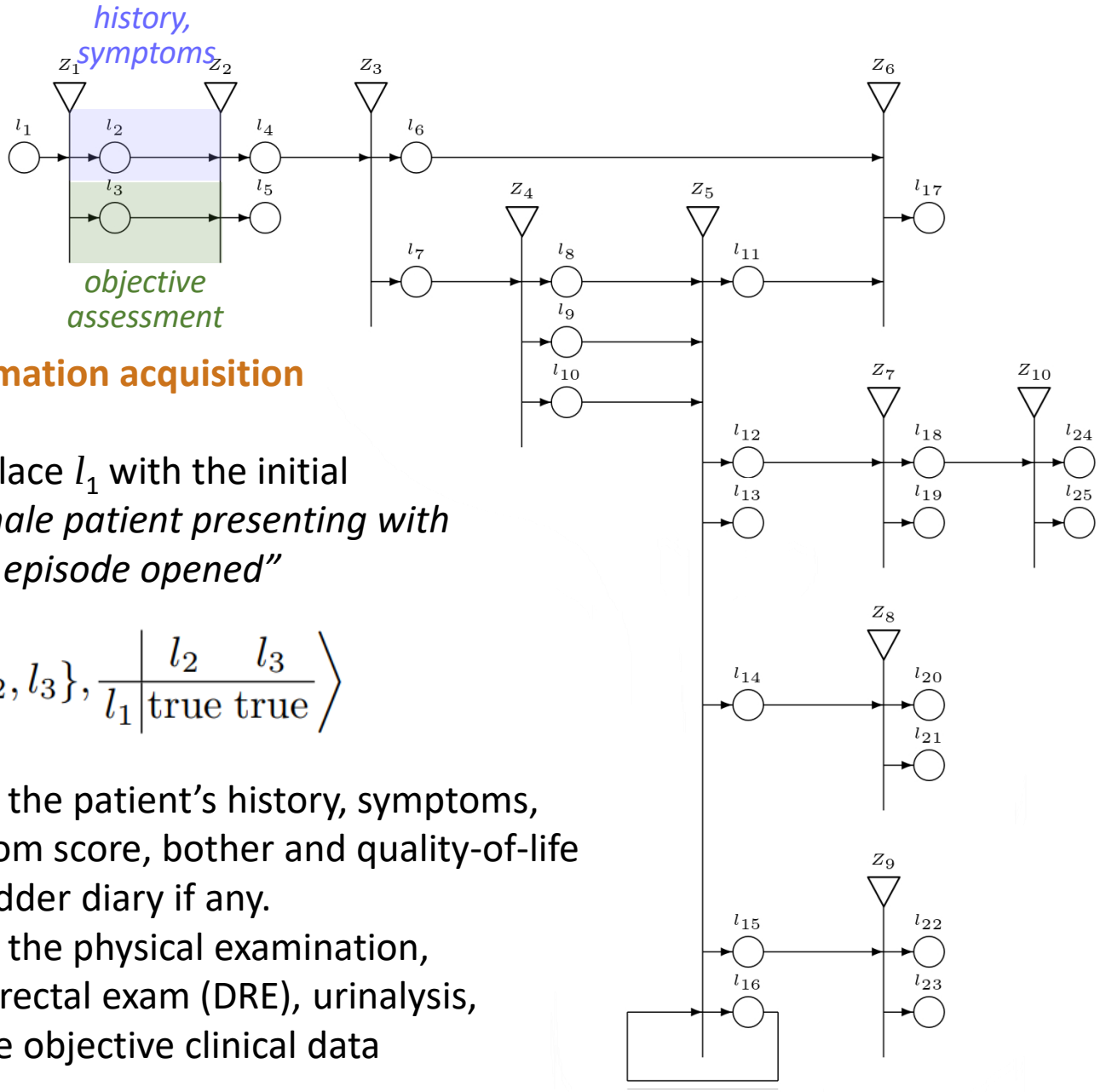
The patient token π

χ_π = ⟨patient, episode, time, history,
symptoms, findings, values, flags,
pathways, hypotheses,
missing information, next step⟩

Information-task tokens

- α: history and symptom assessment
- β: examination and initial objective findings
- γ: non-invasive functional information
- δ: urodynamic status and results
- ε: targeted patient-specific investigations

Generalized Net model architecture



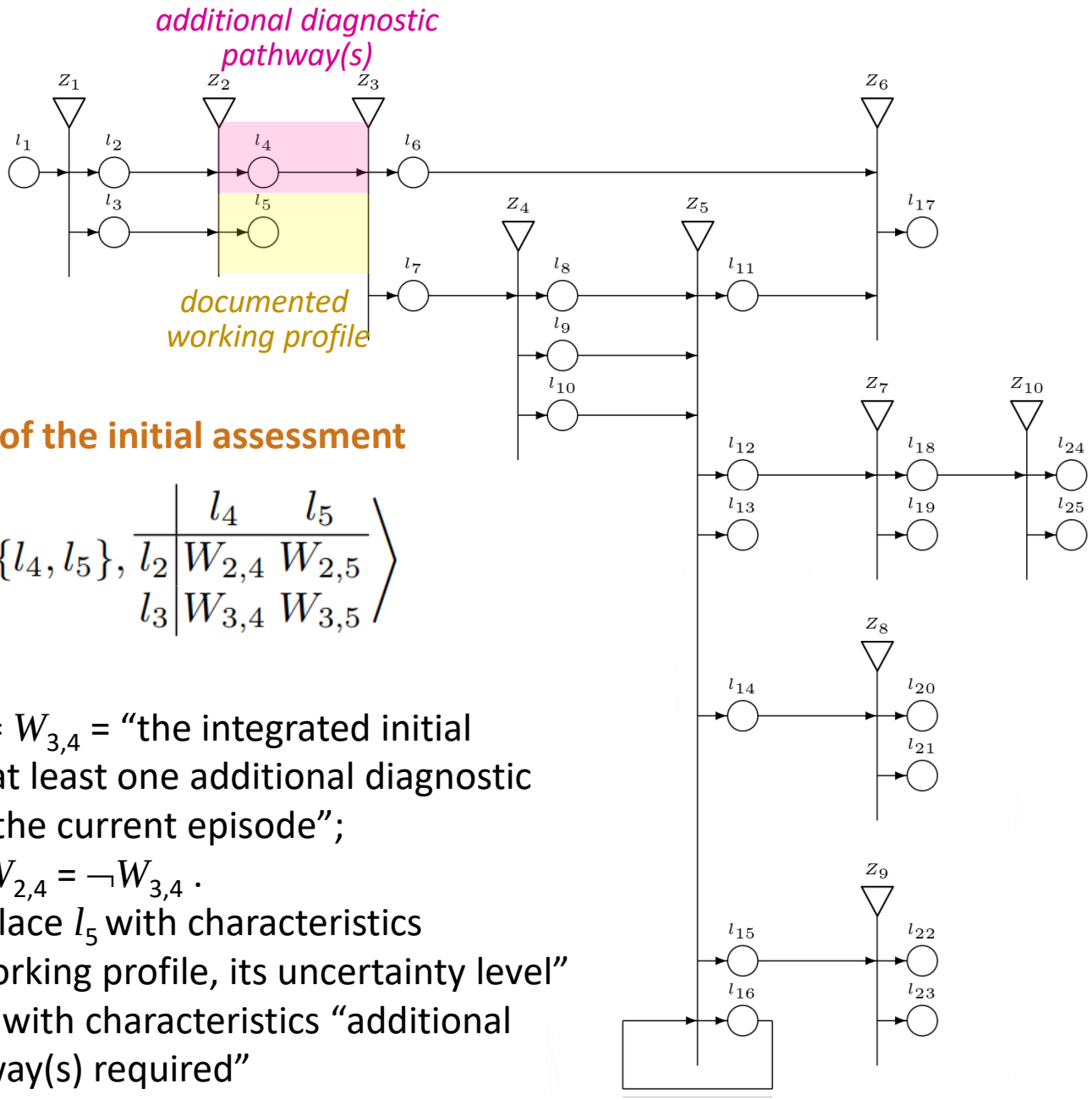
Z_1 – Initial information acquisition

Token π enters place l_1 with the initial characteristic *"male patient presenting with LUTS; diagnostic episode opened"*

$$Z_1 = \left\langle \{l_1\}, \{l_2, l_3\}, \begin{array}{c|cc} & l_2 & l_3 \\ \hline l_1 & \text{true} & \text{true} \end{array} \right\rangle$$

Place l_2 contains the patient's history, symptoms, validated symptom score, bother and quality-of-life information, bladder diary if any.
Place l_3 contains the physical examination, including digital rectal exam (DRE), urinalysis, and any available objective clinical data

Generalized Net model architecture



Z_2 – Integration of the initial assessment

$$Z_2 = \left\langle \{l_2, l_3\}, \{l_4, l_5\}, \begin{array}{c|cc} & l_4 & l_5 \\ \hline l_2 & W_{2,4} & W_{2,5} \\ l_3 & W_{3,4} & W_{3,5} \end{array} \right\rangle$$

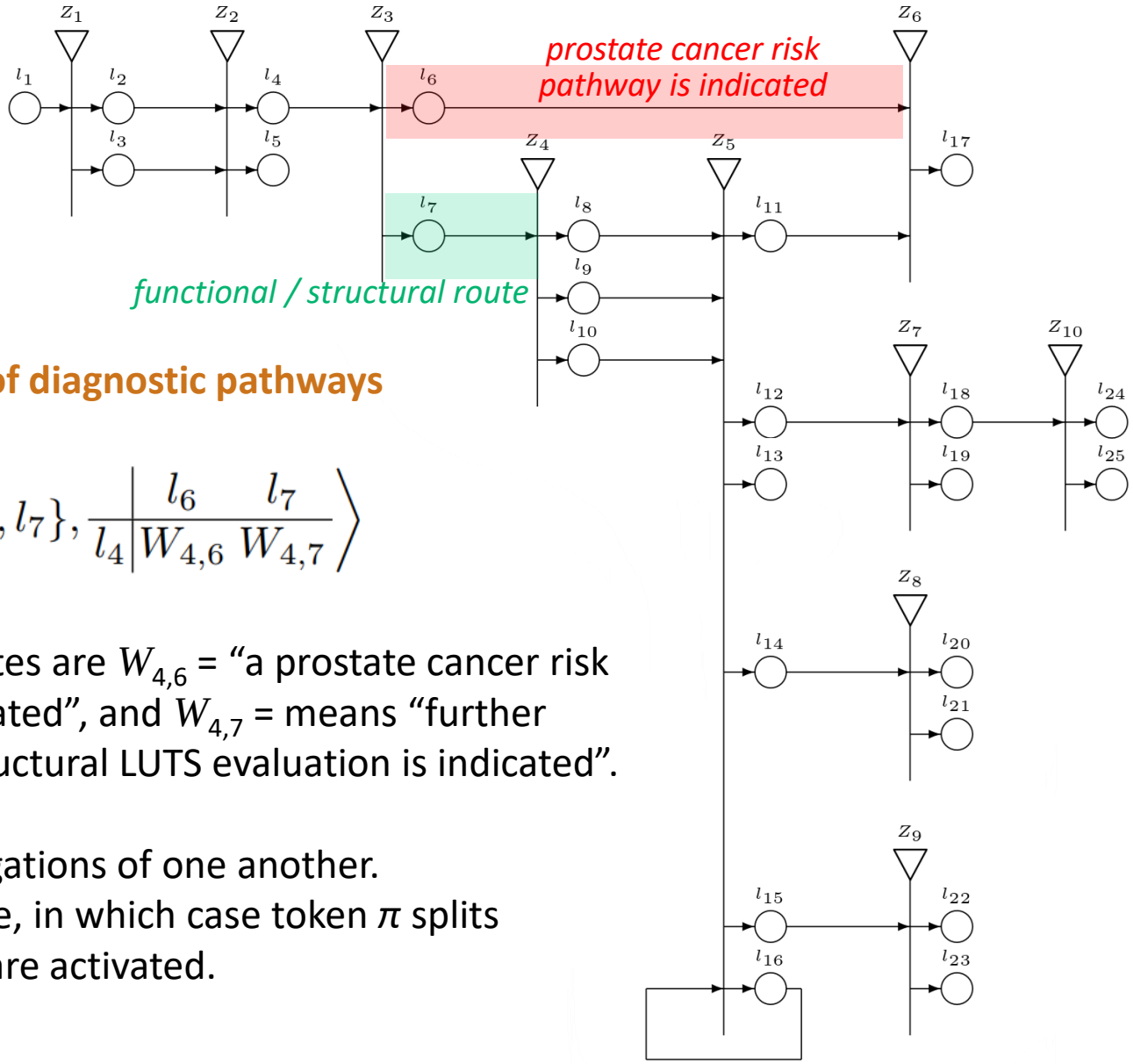
Predicates $W_{2,4}$ = $W_{3,4}$ = “the integrated initial profile requires at least one additional diagnostic pathway during the current episode”;

$W_{2,5}$ = $W_{3,5}$ = $\neg W_{2,4}$ = $\neg W_{3,4}$.

Token π enters place l_5 with characteristics “documented working profile, its uncertainty level”

π enters place l_4 with characteristics “additional diagnostic pathway(s) required”

Generalized Net model architecture



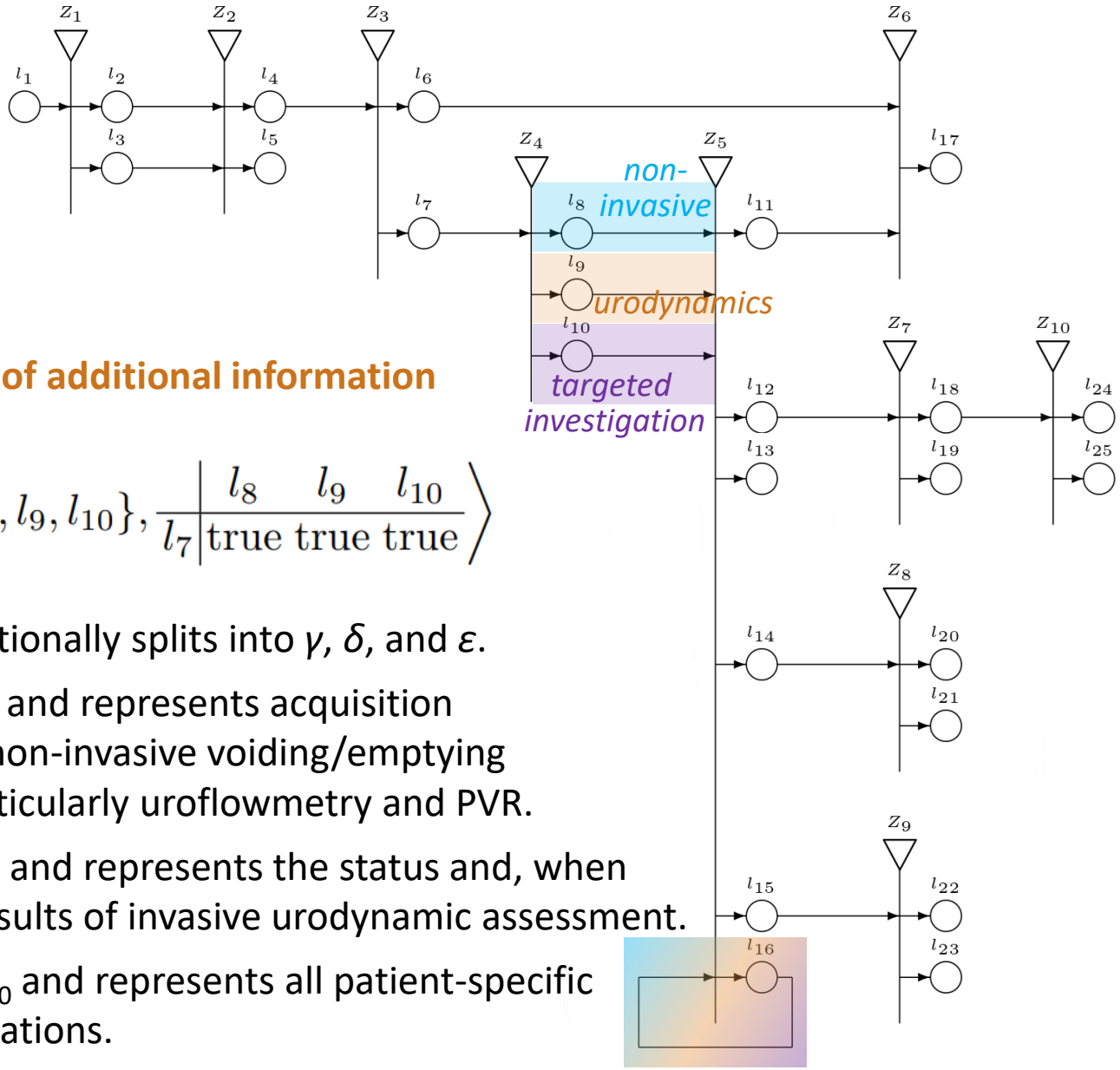
Z_3 – Activation of diagnostic pathways

$$Z_3 = \left\langle \{l_4\}, \{l_6, l_7\}, \begin{array}{c|cc} & l_6 & l_7 \\ \hline l_4 & W_{4,6} & W_{4,7} \end{array} \right\rangle$$

The two predicates are $W_{4,6}$ = "a prostate cancer risk pathway is indicated", and $W_{4,7}$ = means "further functional or structural LUTS evaluation is indicated".

They are not negations of one another.
Both may be true, in which case token π splits and both paths are activated.

Generalized Net model architecture



Z_4 – Generation of additional information tasks

$$Z_4 = \left\langle \{l_7\}, \{l_8, l_9, l_{10}\}, \begin{array}{c|ccc} & l_8 & l_9 & l_{10} \\ \hline l_7 & \text{true} & \text{true} & \text{true} \end{array} \right\rangle$$

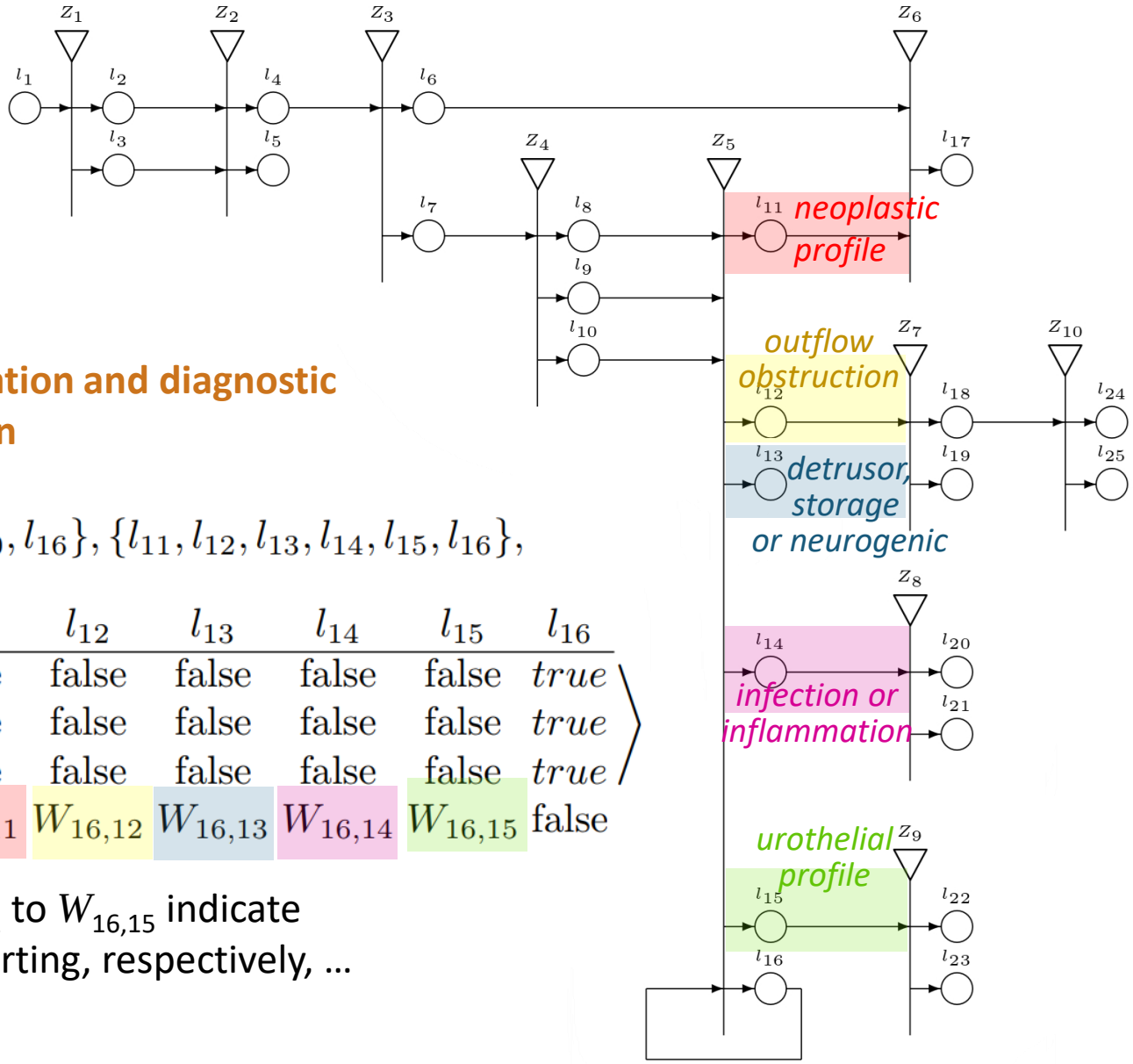
Token π unconditionally splits into γ, δ, and ε.

Token γ enters l_8 and represents acquisition or validation of non-invasive voiding/emptying information, particularly uroflowmetry and PVR.

Token δ enters l_9 and represents the status and, when indicated, the results of invasive urodynamic assessment.

Token ε enters l_{10} and represents all patient-specific targeted investigations.

Generalized Net model architecture



Z_5 – Synchronization and diagnostic classification

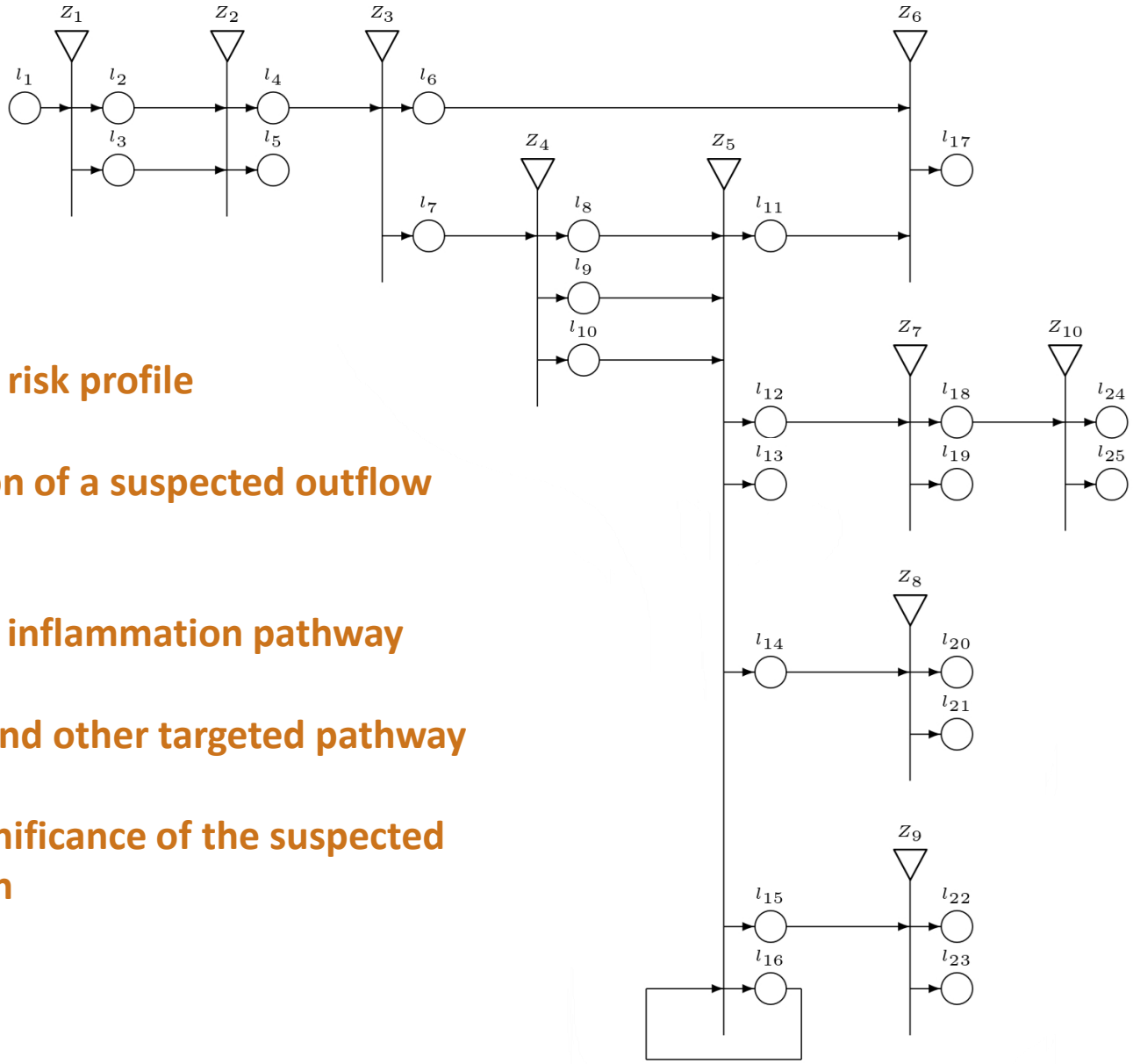
$$Z_5 = \left\langle \{l_8, l_9, l_{10}, l_{16}\}, \{l_{11}, l_{12}, l_{13}, l_{14}, l_{15}, l_{16}\}, \right.$$

	l_{11}	l_{12}	l_{13}	l_{14}	l_{15}	l_{16}
l_8	false	false	false	false	false	$true$
l_9	false	false	false	false	false	$true$
l_{10}	false	false	false	false	false	$true$
l_{16}	$W_{16,11}$	$W_{16,12}$	$W_{16,13}$	$W_{16,14}$	$W_{16,15}$	false

$\left.\right\rangle$

Predicates $W_{16,11}$ to $W_{16,15}$ indicate evidences supporting, respectively, …

Generalized Net model architecture



Z_6 – Oncological risk profile

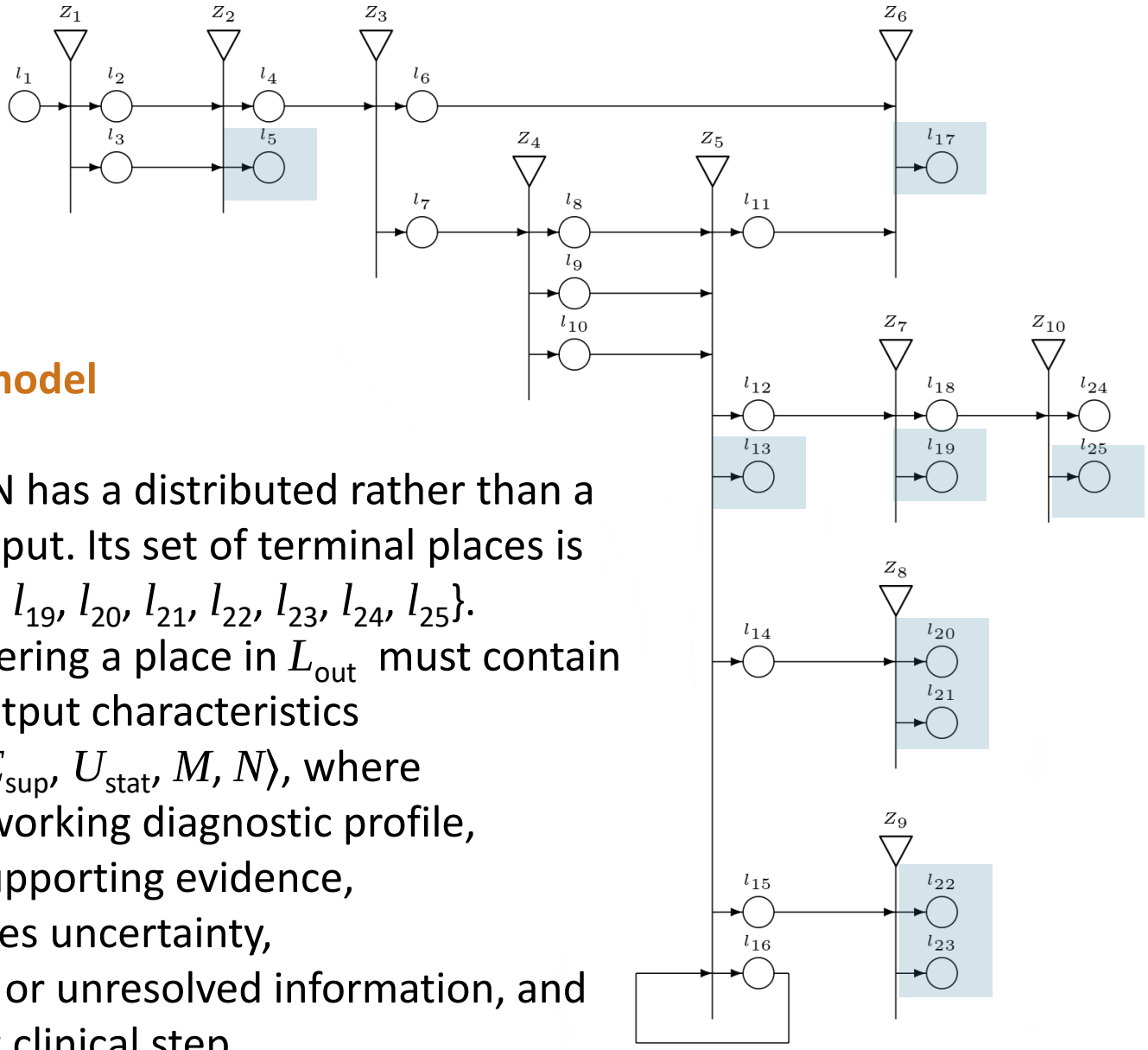
Z_7 – Classification of a suspected outflow obstruction

Z_8 – Infection or inflammation pathway

Z_9 – Structural and other targeted pathway

Z_{10} – Clinical significance of the suspected obstruction

Generalized Net model architecture



Output of the model

The compact GN has a distributed rather than a single-place output. Its set of terminal places is $L_{out} = \{l_5, l_{13}, l_{17}, l_{19}, l_{20}, l_{21}, l_{22}, l_{23}, l_{24}, l_{25}\}$.
Every token entering a place in L_{out} must contain the standard output characteristics
$\chi_{out} = \langle i, H_{work}, E_{sup}, U_{stat}, M, N \rangle$, where

- H_{work} is the working diagnostic profile,
- E_{sup} is the supporting evidence,
- U_{stat} expresses uncertainty,
- M is missing or unresolved information, and
- N is the next clinical step.

Conclusion

The diagnostic evaluation of male LUTS cannot be reduced to a single linear sequence or to an early choice between benign prostatic disease and prostate cancer.

Symptoms may have several simultaneous causes, while the relevance and availability of particular examinations depend on the patient's history, warning features, previous findings, and the quality of the information already obtained.

The proposed Generalized Net model represents these characteristics through parallel token movement, conditional diagnostic branching, and the accumulation of patient-specific information.

Further work should operationalize the predicates using explicit clinical rules and thresholds, uncertainty-aware nomograms, implement the model in software, and evaluate its behaviour using retrospective or prospectively collected patient data. Implementation of GN is possible, for instance on the client-server platform *OnlineGN* that is being developed in IBPhBME-BAS.

Thank you for your attention!

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