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Employing Ensemble Reasoning to Support Clinical Decision-Making

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Computer Science | 04/03/23

- Problem Definition
  - The design, implementation, and analysis of a clinical decision support system that can perform ***ensemble reasoning***, which we define as the integration and interaction of multiple types of reasoning, by emulating a model for clinical reasoning

- Motivation
  - Aiding physicians during the clinical decision-making process by creating an AI system that can reason in a way similar to how physicians reason

Research Questions (1 of 2)

- Are the recommendations derived using our approach clinically relevant for use cases involving clinical reasoning?
- Are the factors used to arrive at recommendations clinically relevant?
- Is it clinically important or advantageous to reveal the recommendation rationale?

Research Questions (2 of 2)

- When considering the interaction of multiple types of reasoners, does the order of reasoning make an impact on the results of the reasoning or the time it takes to obtain the results?
- Does an iterative approach versus an alternating approach make an impact on the results or the time it takes to obtain the results?
- Why might one approach be preferred over the other?
- Is it more efficient to split abducibles into subsets, run the abductive reasoner on each subset, and then combine the results than running an abductive reasoner with all abducibles specied?
- How can all interrelated abducibles be determined?

Research Contributions

- A Concise Ontology to Support Research on Complex, Multimodal Clinical Reasoning
- An Approach for Clinical Decision-Making Employing Ensemble Reasoning
- Clinical Relevance of Therapy Planning Recommendations and Rationales
- A Theoretical Analysis of Ensemble Reasoning

- ***A concise ontology***
  - Adheres to the Minimum Information to Reference an External Ontology Term (MIREOT) principles
  - Follows an agile design methodology
- Design the Diabetes Pharmacology Ontology (DPO)
- Apply the ontology to an application requiring abduction
- Evaluate using CBK Principles and Competency Questions

- Contributions
  - Develop an approach for semantic knowledge representation that supports multimodal reasoning
  - Demonstrate how the approach can be used for clinical decision-making

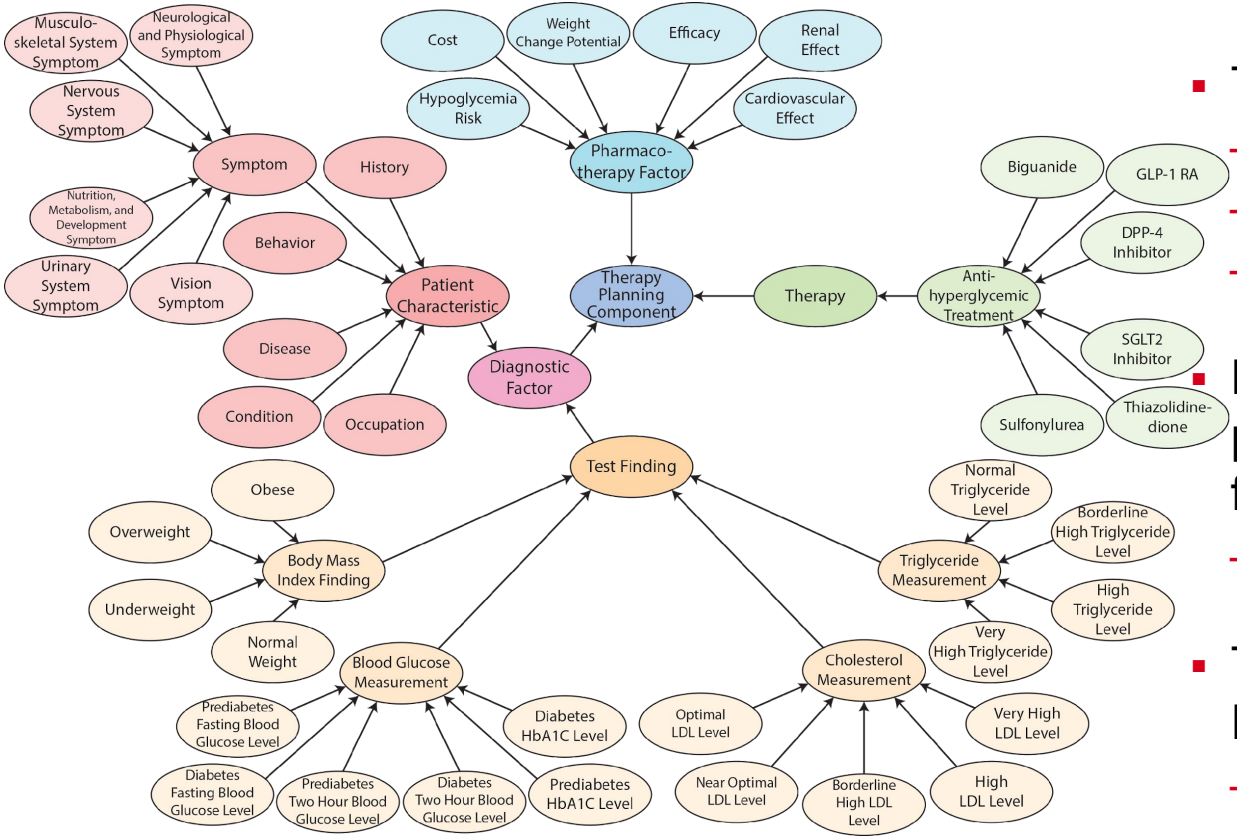
- Claims
  - Use cases that incorporate multiple forms of reasoning are better supported by concise, rather than complete and comprehensive, ontologies
  - Our ontology and Personal Health Knowledge Graph (PHKG) support multimodal reasoning, involving both deduction and abduction, and can demonstrate the emulation of clinical decision-making
  - Our ontology is based on existing standards and that the resources resulting from this research are FAIR

- Motivation
  - Reasoning over large and complex ontologies can be very time-consuming
  - Even worse for non-monotonic reasoning, such as abduction
  - Existing diabetes ontologies focus on completeness
  - We instead design a concise ontology targeted to our use case
- Use Case
  - Support provided should emulate the type of rationality a clinician is likely to apply
  - Proof of concept rather than complete coverage
  - Provided recommendations should align with domain-specific standards
  - Should be scoped around treating type 2 diabetes mellitus
  - Data used should resemble realistic patients

Ontology Design Approach

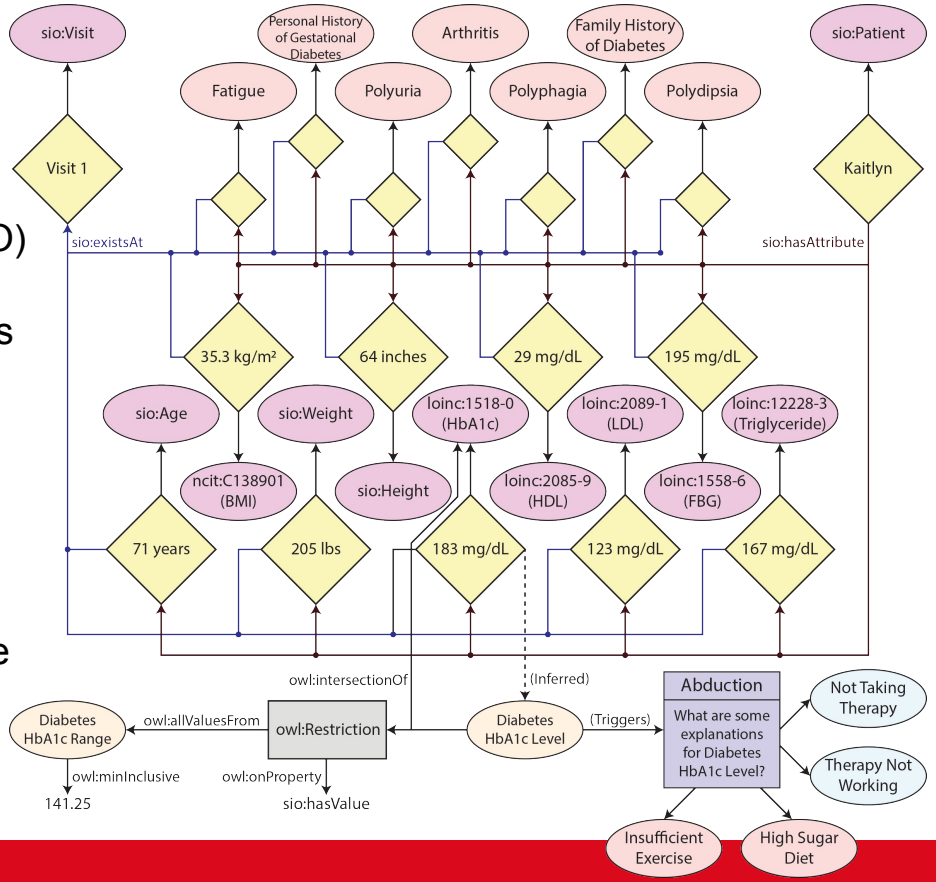
- Needed a structured vocabulary to support our use case
- Employed an agile design strategy
  - Simplicity is encouraged
  - Essential features should be implemented foremost, while additional features can be included later
  - Initially only include concepts and properties that are essential for the particular task
- Scoping
  - Standards of Medical Care in Diabetes Clinical Practice Guidelines by the American Diabetes Association
  - In particular, factors and therapies in Chapter 9: Pharmacologic Approaches to Glycemic Treatment
  - Diagnostic factors and clinical measurements included in diabetes-related NetCE case studies
- Linked external vocabularies based on MIREOT principles

Diabetes Pharmacology Ontology (DPO)



- Therapy Planning Component
  - Pharmacotherapy Factor
  - Diagnostic Factor
  - Therapy
- Diagnostic Factors include patient characteristics and test finding
  - Based on NetCE example patients
- Therapies and Pharacotherapy Factors
  - Based on ADA Guidelines Chap. 9

- Semantic Representation of Hypothetical Patient Data
  - Semanticscience Integrated Ontology (SIO)
  - Fast Healthcare Interoperability Resources (FHIR)
  - Includes patient attributes, symptoms and conditions, measurements, and temporal information, such as visits
  - Used to test both Deductive and Abductive rules



Evaluation

- Guiding principles for developing computational biomedical knowledge (CBK) and infrastructure
  - FAIR, trustworthy, and open
  - https://tetherless-world.github.io/diabetes-pharmacology-ontology/#supplementary-material
- Competency Questions
  - C_1: What are some causes for an HbA1c level in the diabetes range?
  - C_2: How can we explain the patient having insufficient exercise?
  - C_3: Why might the patient not be talking a medication?
  - C_4: What therapies have high efficacy?
  - C_5: What therapies have potential for weight loss?
  - C_6: What therapies have potential atherosclerotic cardiovascular disease benefit?

What are some causes for an HbA1c level in the diabetes range?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_1	0	∞	1	1.01	N/A	N/A	4	HbA1c
			2	1.01	14.2	N/A	9	
			3	1.14	14.65	T/O	9	
	1	18	1	**0.91**	N/A	N/A	4	
			2	1.04	11.52	N/A	9	
			3	0.92	11.67	T/O	9	
	2	12	3	1.44	6.04	**49.04**	9	

How can we explain the patient having insufficient exercise?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_2	0	∞	1	0.39	N/A	N/A	3	Exercise
			2	0.38	0.66	N/A	3	
			3	0.39	0.66	1.33	3	
	1	9	1	0.38	N/A	N/A	3	
			2	**0.36**	**0.45**	N/A	3	
			3	0.39	0.49	**0.49**	3	

Why might the patient not be talking a medication?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_3	0	∞	1	0.49	N/A	N/A	6	Comply
			2	0.46	0.93	N/A	6	
			3	0.58	0.94	2.23	6	
	1	11	1	0.48	N/A	N/A	6	
			2	**0.38**	**0.48**	N/A	6	
			3	0.57	0.57	**0.57**	6	

What therapies have high efficacy?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_4	0	∞	1	T/0	N/A	N/A	0	Therapy
	1	26	1	8.26	N/A	N/A	14	
			2	8.47	T/O	N/A	14	
	2	13.5	2	7.64	T/O	N/A	14	
	3	9.33	2	7.95	49.52	N/A	14	
			3	**7.4**	**48.75**	T/O	14	

What therapies have potential for weight loss?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_5	0	∞	1	T/0	N/A	N/A	1	Therapy
	1	26	1	7.76	N/A	N/A	11	
			2	7.25	T/O	N/A	12	
	2	13.5	2	6.86	T/O	N/A	12	
	3	9.33	2	**6.59**	**48.42**	N/A	11	
			3	7.07	48.95	T/O	12	

What therapies have potential ASCVD benefit?

CQ	# Segments	# Abd / Seg	Depth	t_1(s)	t_2(s)	t_3(s)	# Exps	Module
C_6	0	∞	1	T/0	N/A	N/A	0	Therapy
	1	26	1	6.96	N/A	N/A	7	
			2	6.75	T/O	N/A	8	
	2	13.5	2	**5.68**	T/O	N/A	9	
	3	9.33	2	6.1	51.53	N/A	7	
			3	6.07	**50.51**	T/O	12	

Discussion

- Evaluation
  - Evaluated the capability of competency questions to be answered abductively
  - Results demonstrate the importance of conciseness when performing abductive reasoning
  - Smaller modules allowed for abductive answers to be obtained faster and to a greater depth
  - Discovered greater depth calculations could be obtained by dividing the set of abducibles into subsets
- Impact
  - Approach to designing concise rather than complete ontologies
  - Openly published associated resources
  - Helping address a prevalent health problem affecting 37.3 million people in the United States
- Limitations related to not being comprehensive

An Approach for Clinical Decision-Making Employing Ensemble Reasoning

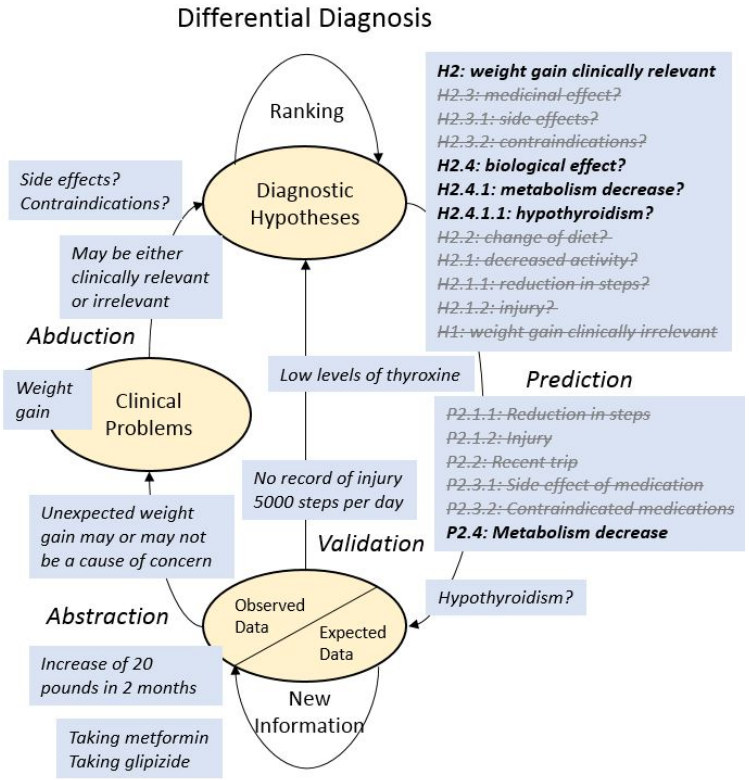
- Designed and implemented a clinical decision support system
  - Incorporates ***ensemble reasoning***
  - Based on Select and Test Model
  - Supports differential diagnosis and therapy planning (and arguable plan critiquing)
  - Evaluation involving comparing decision trees

- Contributions
  - Define ***ensemble reasoning*** as the integration and interaction of multiple types of reasoning
  - Design, implement, and integrate various reasoning components to create a semantic workflow for ensemble reasoning based on a clinical reasoning model
  - Define metrics for comparing multiple decision trees
  - Each agent developed to perform components of the ST-Model

- Claims
  - Ensemble reasoning can be used to perform tasks involving clinical reasoning, such as differential diagnosis and therapy planning
  - Therapy recommendations obtained by our therapy planner are comparable to the ADA guidelines recommendations

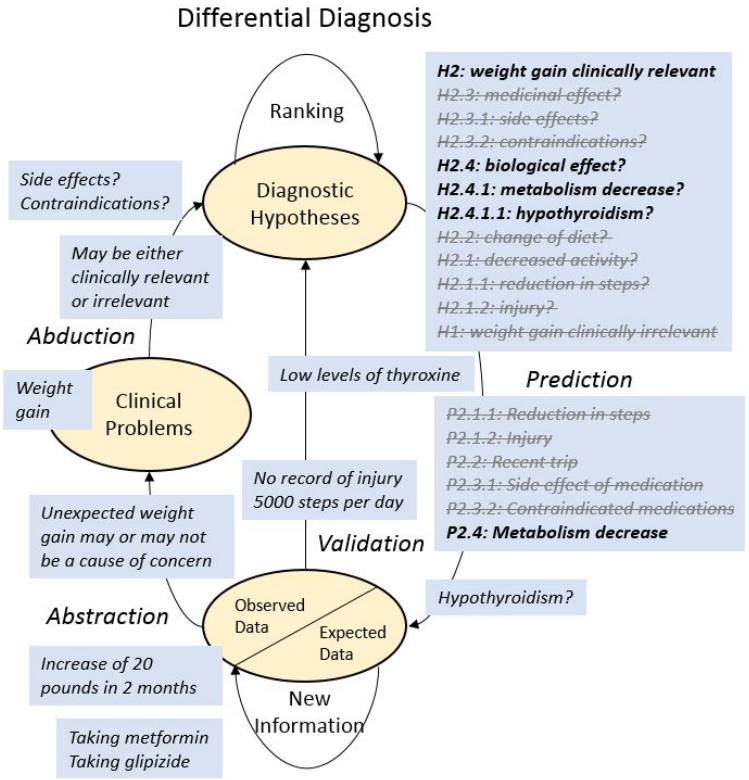
- Motivation
  - Address thesis goal of creating of a decision-making system that can support clinicians
  - Aid in the dissemination of large amounts of data, such as in guidelines
  - Create an AI system that reasons in a way similar to physicians
- Leverages Select and Test Model (ST-Model)
- Reasoning Agents are designed to emulate various ST-Model reasoning components
- Therapy Planning results in treatment recommendations
  - Rationales for Recommendations
  - Transparency and Traceability

Select and Test Model (ST-Model)



- Unexpected weight gain example
  - The patient gained 20 pounds in 2 months.
  - She was originally 130 at the last visit, but at 150 pounds she is now slightly overweight for her height and age, approaching pre-obese status.
  - Was this weight gain intentional or unintentional? Typically people her age do not intend to gain weight, but it may be worth asking. What could be some other causes if the weight gain was unintentional?
  - What could be some other causes if the weight gain was unintentional?
  - There are four common explanations for weight gain that are worth considering. 1) Maybe there has been a decrease in the amount of activity. Is there a record of injury? Maybe we can get some IoT data. 2) It is possible her diet has changed over the past 2 months. 3) Possibly could be a medicinal side effect or contraindication. 4) It also may be biological. She is getting older after all, her metabolism may be decreasing.

Select and Test Model (ST-Model)



- Unexpected weight gain example
  - I reached out to the patient, and she confirmed that she did not intend to gain weight. I did not find any mention of a recent injury in her records. While searching, I was able to get some of her IoT data. She is still averaging 5000 steps per day.
  - She also mentioned she had a holiday recently, but did not travel during it. She believes her diet is more or less the same as before.
  - I noticed that the patient is taking several medications for diabetes, including glipizide and metformin. We should look for weight gain as a side effect for one of the medications.
  - The side effects of these drugs do not include weight gain. They also are not contraindicating with any other medications she is known to be taking.
  - We've crossed out most of the possibilities and are just left with a biological effect being a likely cause. Will order a TSH (thyroid-stimulating hormone) test.
  - ***We found low levels of the thyroid hormone, thyroxine. The thyroid is indeed underactive.***

Approach

- Build agents using Whyis
  - Knowledge management framework that supports research and development of semantic applications
  - Allows provenance information to be captured in Nanopublications
  - Independent design agents to handle various reasoning tasks
- SQuARE (**S**PARQL **Qu**ery **A**gent-based **R**easoning **E**ngine)
  - Implemented our own SPARQL query-based deductive inference engine
  - Allows for custom reasoning which was used to encode clinical rules
  - Available as a python package: https://pypi.org/project/twc-square/
- Integrated existing abductive reasoner
  - AAA Abox Abduction Solver
  - Parse output and convert to RDF

Differential Diagnosis via Truth Maintenance

Algorithm 1 Truth Maintenance Algorithm – TruthMaintenance(Observation)

```
Require: Observation = Unsupported
  Can we refute it?                                   ▷ Does a contradiction exist?
  if Yes then
      Observation ← Rejected
      return
  else if No then
      continue
  end if
  Can we support it?                                  ▷ Does direct evidence exist?
  if Yes then
      Observation ← Supported
      continue
  else if No then
      continue
  end if
  Can we explain the observation?
  if Yes then
      Is there an associated abductive module?        ▷ Optimization to prevent running
  against the entire graph
      if Yes then
          Explanations ← AbductionAgent(Observation)
          for Explanation in Explanations do
              TruthMaintainance(Explanation)
          end for
      else if No then
          return
      end if
  else if No then
      return
  end if
```

- Iterate through potential explanations
- Searches for direct evidence
- Use evidence to support or reject hypotheses that are initially unsupported
- Recursively find explanations and try to support them
- Looks for existing modules as an optimization

Therapy Planning via Query-based Ranking

- Designed and Implemented an Agent to perform therapy planning
- Uses simple ranking approach
  - Assigns values to therapies based on pharmacotherapy factor associations
  - Associations can be inferred from patient data
  - All weights are equal
- Recommendations are supported by rationales
- Results are returned as a python dictionary

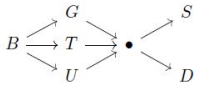
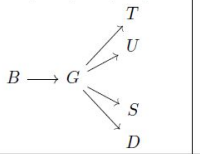
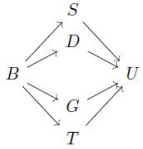
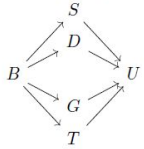
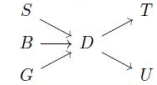
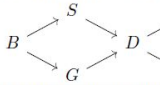
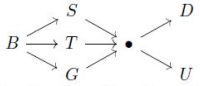
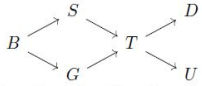
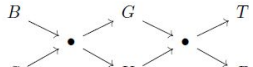
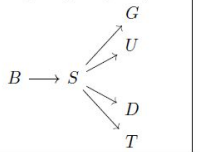
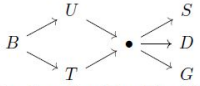
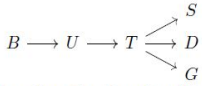
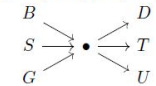
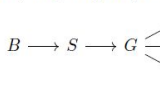
```
'http://purl.org/twc/dpo/kb/PatientK': {
 'Therapy Rankings':
  [('Biguanide',2), ('Thiazolidinedione',1), ('GLP-1 RA',1),
  ('Sulfonylurea',1), ('SGLT2 Inhibitor' 0), ('DPP-4 Inhibitor',-1)],
 'Aversions': {
   'http://purl.org/twc/dpo/ont/LowEfficacyDiabetesTherapy': {},
   'http://purl.org/twc/dpo/ont/HighCostDiabetesTherapy': {
'SGLT2 Inhibitor': '-1',
'GLP-1 RA': '-1',
'DPP-4 Inhibitor': '-1' },
   'http://purl.org/twc/dpo/ont/WeightGainDiabetesTherapy': {
'Thiazolidinedione': '-1',
'Sulfonylurea': '-1' } },
 'Preferences': {
   'http://purl.org/twc/dpo/ont/WeightLossDiabetesTherapy': {
'SGLT2 Inhibitor': '+1',
'GLP-1 RA': '+1' },
   'http://purl.org/twc/dpo/ont/LowCostDiabetesTherapy': {
'Thiazolidinedione': '+1',
'Biguanide': 'Metformin',
'Sulfonylurea': '+1' },
   'http://purl.org/twc/dpo/ont/HighEfficacyDiabetesTherapy': {
'Thiazolidinedione': '+1',
'Biguanide': 'Metformin',
'GLP-1 RA': '+1',
'Sulfonylurea': '+1' } } }
```

Evaluation

- Compared against 2022 ADA guideline recommendations
- A patient created for each of the pharmacotherapy factors considered
  - 28 test patients created
  - 7 patients assigned a preference for a single therapy factor
  - 21 patients assigned preferences for two factors
- Recommendations normalized
- Two evaluation metrics used
  - M1 - Starting from 0, for each treatment category that has a different value between rankings, the score is incremented by 1
  - M2 - starting with a score of 0, a value of 1 is added for each traversal of a node within a ranking tree for one system that needs to be made to align with the other ranking system

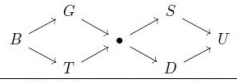
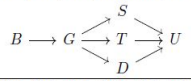
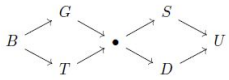
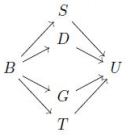
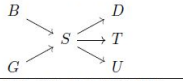
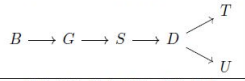
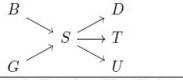
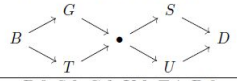
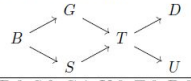
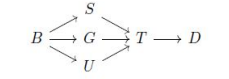
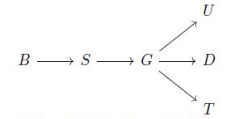
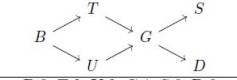
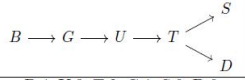
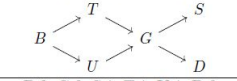
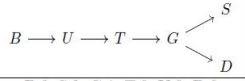
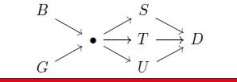
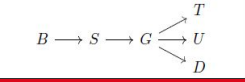
Single-Factor Evaluation

- When considering a single factor, our system performed pretty well
- Exact match for Hypoglycemia recommendation
- Worst-case difference of 3 for both metrics

Factor	System Ranking	ADA Rankings	M_1	M_2
Efficacy	B:2, G:1, T:1, U:1, S:0, D:0 	B:2, G:1, T:0, U:0, S:0, D:0 	2	2
Hypoglycemia	B:2, S:1, D:1, G:1, T:1, U:0 	B:2, S:1, D:1, G:1, T:1, U:0 	0	0
Weight	B:2, S:2, G:2, D:1, T:0, U:0 	B:3, S:2, G:2, D:1, T:0, U:0 	1	1
ASCVD	B:2, S:1, G:1, T:1, D:0, U:0 	B:3, S:2, G:2, T:1, D:0, U:0 	3	1
Heart Failure	B:2, S:2, G:1, U:1, D:0, T:0 	B:2, S:1, G:0, U:0, D:0, T:0 	3	3
Cost	B:2, U:1, T:1, S:0, D:0, G:0 	B:3, U:2, T:1, S:0, D:0, G:0 	2	1
DKD	B:1, S:1, G:1, D:0, T:0, U:0 	B:3, S:2, G:1, D:0, T:0, U:0 	2	2

Dual-Factor Efficacy Evaluation

- Results for one of 7 dual-factor evaluations shown here
- Did not perform as well as single factor evaluation
- This is expected, since we weigh each factor equally while ADA flowchart has preference for treating high risk factors

Factors	System Ranking	ADA Rankings	M_1	M_2
Efficacy & Hypoglycemia	B:3, G:2, T:2, S:1, D:1, U:0 	B:3, G:2, T:1, S:1, D:1, U:0 	1	2
Hypoglycemia & Efficacy	B:3, G:2, T:2, S:1, D:1, U:0 	B:2, S:1, D:1, G:1, T:1, U:0 	3	2
Efficacy & Weight	B:2, G:2, S:1, D:0, T:0, U:0 	B:4, G:3, S:2, D:1, T:0, U:0 	4	2
Weight & Efficacy	B:2, G:2, S:1, D:0, T:0, U:0 	B:3, S:2, G:2, D:1, T:0, U:0	3	2
ASCVD & Efficacy	B:3, G:2, T:2, S:1, U:1, D:0 	B:3, G:2, S:2, T:1, U:0, D:0 	3	3
Heart Failure & Efficacy	B:3, S:2, G:2, U:2, T:1, D:0 	B:3, S:2, G:1, U:0, T:0, D:0 	3	4
Efficacy & Cost	B:3, T:2, U:2, G:1, S:0, D:0 	B:4, G:3, U:2, T:1, S:0, D:0 	3	4
Cost & Efficacy	B:3, T:2, U:2, G:1, S:0, D:0 	B:4, U:3, T:2, G:1, S:0, D:0 	2	1
DKD & Efficacy	B:2, G:2, S:1, T:1, U:1, D:0 	B:3, S:2, G:1, T:0, U:0, D:0 	5	5

Compilation of Evaluation of Treatment Planning Results

Precedent Factor	M_1		M_2	
	μ	σ	μ	σ
Single Factor	**1.857**	**0.990**	**1.429**	**0.904**
Efficacy	3	1.054	2.778	1.227
Hypoglycemia	2.667	0.943	2	0.471
Weight	3.444	0.956	2.667	0.816
ASCVD	2.625	0.992	2.125	0.927
Heart Failure	2.875	0.927	2.875	0.781
Cost	3.333	0.943	3	1.247
DKD	3	1.323	3	1.323
Dual-Factor Average	**2.992**	**1.020**	**2.635**	**0.970**

Discussion

- Implemented an ensemble reasoning system based on ST-Model
- Defined two metrics for comparing decision trees
- Evaluated results of therapy planning against ADA guidelines
- Limitations and Future Work
  - Designed truth maintenance algorithm but haven't yet implemented it
  - Full workflow isn't automated – some agents have to be manually triggered
  - Therapy planning agent ranking approach is too simple, should have better weighting of factors
  - Additional representation considerations, such as more detailed recording of provenance

Clinical Relevance of Therapy Planning Recommendations and Rationales

- Designed an IRB approved study
- Interviewed clinicians to evaluate the clinical relevance of recommendations and rationale
- Received a lot of valuable feedback
- Interesting Discussions
- Compiled and analyzed results

- Contributions
  - Design and organization of a study for evaluating the clinical relevance of our system recommendations and justifications
  - The artifacts used for the interviews
  - Compilation and analysis of the results of the evaluation

- Claims
  - The recommendations resulting from our therapy planner are clinically relevant
  - The factors identified by our the system used to arrive at the recommendations are clinically relevant
  - The ability to see system rationale is important to clinicians

- Designed a study to collect feedback from clinicians
  - Open Response Questions
  - Questions using a Likert Scale
- Motivation
  - Evaluate the clinical relevance of our therapy planning approach
  - Clinical relevance of recommendations
  - Clinical relevance of factors and rationales used to arrive at recommendations
- Resulted in several useful artifacts
- Received valuable feedback for future improvements and extensions

Study Method

- Participants
  - Hoped for at least 7 but managed to retain all 10
  - Primary care physician with experience treating diabetes
  - Currently in practice
  - Aware and up to date with ADA guidelines
- Screening
  - Screening form used to find participants matching the eligibility criteria
- Informed Consent
- Interviews

- Open Response Questions
  - OQ_1 - Do you have any immediate thoughts about this patient?
  - OQ_2 - Is there anything else that would be important to know?
  - OQ_3 - Are there any facts the system missed that you would have deemed relevant?
  - OQ_4 - Are there other things the system should have considered?
  - OQ_5 - Are you more likely to trust a system that includes insights for its recommendations?
  - OQ_6 - What kinds of improvements and additional capabilities would you like to see in an AI system like this?
  - OQ_7 - What is your general view of AI systems and their impact on the practice of medicine?
  - OQ_8 - Do you have any overall suggestions or recommendations for improvement?

- Likert Scale Questions
  - LQ_1 - The factors the system identified are clinically relevant.
  - LQ_2 - The system's recommendations are clinically appropriate for this patient.
  - LQ_3 - Overall, the system recommendations about patients were clinically relevant.
  - LQ_4 - The ability to see system rationale is important.

- Likert Scale
  - Strongly Agree = 2
  - Agree = 1
  - Neither Agree Nor Disagree = 0
  - Disagree = -1
  - Strongly Disagree = -2

Patient K

- Visit 1 (8 months ago)
  - Patient K is a 71-year-old obese white woman on a fixed income who presents with complaints of fatigue, polyuria, polyphagia, and polydipsia. Labs are ordered, which indicated an HbA1c of 8.0%. Her physician recommends a change of diet and an increase in exercise and provides a referral to a nutritionist.
- Visit 2 (4 months ago)
  - Patient K revisits after four months. She admits to having trouble adhering to the exercise plan, due to pain in her knees. She has not been able to follow the recommended diet. Labs are drawn and her HbA1c increased to 8.6%. In response, her physician prescribes her metformin.
- Visit 3 (Today)
  - Patient K visits today, four months after her last visit. She says she has been taking metformin regularly. She has gained weight, which she attributes to eating over the holidays. Her labs indicate that her HbA1c has increased to 9.1%.

Patient H

- Visit 1 (6 months ago)
  - Patient H is a 38-year-old obese African American woman who has no active health issues. At her annual exam, labs were ordered and she was found to have an HbA1c of 7.8%. Her physician recommends a change to her diet and an exercise plan.
- Visit 2 (3 months ago)
  - After three months, a HbA1c test was ordered and remained close to the initial value at 7.8% despite following the diet and exercise plan. In response, metformin was prescribed.
- Visit 3 (Today)
  - At her next visit, three months later, her HbA1c increased slightly to 8.0%. Patient H says she is regularly taking metformin.

Patient B

- Visit 1 (Today)
  - Patient B is a 64-year-old overweight Pacific Islander woman who presents with new complaints of dysuria, polyuria, and fatigue. She has been previously diagnosed with chronic kidney disease after having recurrent pyelonephritis. She also has mild hypertension. Labs were drawn and showed an elevated HbA1c of 7.8%.

- Problem List
  - Chronic Kidney Disease, Stage 2
  - Hypertension, Mild
  - Family History of Diabetes

- Vital Signs
  - **Height:** 5’ 1”
  - **Weight:** 155 lbs
  - **BMI:** 29.3 kg/m2
  - **SBP:** 145 mmHG
  - **DBP:** 93 mmHG

- Labs
  - **HbA1c:** 7.8% (177 mg/dL)
  - **Fasting blood glucose:** 147 mg/dL
  - **eGFR:** 80
  - **Triglycerides:** 167 mg/dL
  - **LDL:** 199 mg/dL
  - **HDL:** 32 mg/dL

- Medications
  - ACE Inhibitor

Patient K Recommendations and Rationale

		Treatment Factor		
Medication	**Recommendation**	**Efficacy**	**Cost**	**Weight Change**
Metformin	CONTINUE	High	Low	Neutral
Thiazolidinedione	OPTION TO ADD	High	Low	Gain
Sulfonylurea	OPTION TO ADD	High	Low	Gain
GLP-1 RA	OPTION TO ADD	High	High	Loss
SGLT2 Inhibitor	ALSO EVALUATED	Moderate	High	Loss
DPP-4 Inhibitor	ALSO EVALUATED	Moderate	High	Neutral

Patient H Recommendations and Rationale

		Treatment Factor	
Medication	**Recommendation**	**ASCVD**	**Weight Change**
Metformin	CONTINUE	Benefit	Neutral
GLP-1 RA	OPTION TO ADD	Benefit (Dulaglutide, Liraglutide, Semaglutide)	Loss
SGLT2 Inhibitor	OPTION TO ADD	Benefit (Empagliflozin, Canagliflozin)	Loss
Thiazolidinedione	ALSO EVALUATED	Benefit (Pioglitazone)	Gain
Sulfonylurea	ALSO EVALUATED	Neutral	Gain
DPP-4 Inhibitor	ALSO EVALUATED	Neutral	Neutral

Patient H Recommendations and Rationale

		Treatment Factor	
Medication	**Recommendation**	**No Prior Therapy**	**CKD**
Metformin	OPTION TO ADD	Preferred	Neutral
GLP-1 RA	OPTION TO ADD	Not Preferred	Benefit (Dulaglutide, Liraglutide, Semaglutide)
SGLT2 Inhibitor	OPTION TO ADD	Not Preferred	Benefit (Empagliflozin, Canagliflozin, Dapagliflozin)
Sulfonylurea	ALSO EVALUATED	Not Preferred	Neutral
Thiazolidinedione	ALSO EVALUATED	Not Preferred	Neutral
DPP-4 Inhibitor	ALSO EVALUATED	Not Preferred	Neutral

Result of Likert Score-Based Questions

Participants	1	2	3	4	5	6	7	8	9	10	μ	σ
Patient K												
LQ_1	2	2	1	2	2	2	2	2	1	2	**1.8**	**0.40**
LQ_2	2	2	-2	1	-2	-2	2	1	-1	1	**0.2**	**1.66**
Patient H												
LQ_1	1	2	1	2	2	0	2	2	2	2	**1.6**	**0.66**
LQ_2	2	2	1	2	2	2	2	2	2	2	**1.9**	**0.30**
Patient B												
LQ_1	1	2	1	-1	1	2	2	1	2	2	**1.3**	**0.90**
LQ_2	-1	0	1	-1	2	1	-1	1	-1	1	**0.2**	**1.08**
Overall												
LQ_3	1	2	1	-1	2	1	2	1	1	2	**1.2**	**0.87**
LQ_4	2	-1	1	1	2	0	2	2	2	2	**1.3**	**1.00**

Discussion

- Results supported our claims
- Interesting discussions
  - AI as a tool
  - A second set of eyes
  - AI for training
  - New guidelines and medications
  - Streamlining mundane tasks
- Limitations
  - Situation Awareness
  - Missing data, considerations, therapies, factors, and associations
  - Improved weighting to incorporate factor preference

Quotes

- “I think that the factors that need to be considered are not equal. I don’t think that cost is as important as weight gain nor is it as important as the ability to reduce cardiovascular events.”

- “I think it’s essential because if you don't have that ability to watch the rationale through or see the process through for the making, you can make erroneous decisions much more easily if you don’t see why the thought was made and it helps you clarify your choice by understanding the rationale for it.”

- “I think AI is very frightening. I think AI needs to be regulated by the government. I think everyone is talking about allowing AI to run unbridled through the system and I have seen statistics that suggest that 50% of jobs over the next 5 to 10 years are going to be replaced by AI. What kind of cultural upheaval is that going to create in this country? Just because we can allow AI to do these things, should we be doing it? I think there are some serious ethical issues that are being ignored right now.”

Quotes

- “I think for someone who doesn't have a differential or doesn’t have experience, who’s actually spending more time asking questions of why and why and why, then this would be a phenomenal learning tool to gather that type of thought process of, ‘What should I be thinking of?’, ‘What care should I be doing?’, ‘What should I do?’, and that would give them the resources to see where their knowledge deficit may be.”

- “It’s fine if the medicine can raise people from the dead, it’s fine, but if you can’t get the prior authorization through, it doesn’t matter that it can raise them from the dead, that it's a good medicine.”

- “I think it should probably include things like, ‘Has the patient had their eye exam yet?’ -- kind of the boring, unsexy things we forget about all the time.”

- “The system’s only as good as all the detail that’s put into it.”

A Theoretical Analysis of Ensemble Reasoning

- Used logic to construct theoretical proofs
  - Impact of reasoning order
  - Impact of reasoning approach
  - Impact of subsetting abducibles
  - Determination of interrelated abducibles

- Contributions
  - Analysis of the impact of reasoning order
  - Analysis of the impact of reasoning approach
  - Analysis of the impact of subsetting abducibles
  - Analysis on the determination of interrelated abducibles

- Claims
  - The order of execution of the different types of reasoners does not make a significant impact on the reasoning time
  - The approach to ensemble reasoning doesn't make a significant impact on the reasoning time
  - It is more efficient to split abducibles into subsets that run abductive reasoner full set of abducibles
  - It is possible to determine interrelated abducibles

Discussion

- Answered remaining research questions using logical proofs
- Analyzing impact of reasoning order to determine if the order of reasoning makes a significant impact on results or reasoning time
- Analyzed the impact of the reasoning approach for ensemble reasoning
  - Iterative approach
  - Alternating approach
- Analyzed impact of splitting abducibles into subsets
- Analyzed ability to determine interrelated abducibles

Impact of Reasoning Order

- PowerPoint's main objective is to augment and illustrate a verbal lecture or talk
- It is presentation tool used to enhance and illustrate your message

Impact of Reasoning Approah

- PowerPoint's main objective is to augment and illustrate a verbal lecture or talk
- It is presentation tool used to enhance and illustrate your message

Impact of Subsetting Abducibles

- PowerPoint's main objective is to augment and illustrate a verbal lecture or talk
- It is presentation tool used to enhance and illustrate your message

Analysis of Interrelated Abducibles

- PowerPoint's main objective is to augment and illustrate a verbal lecture or talk
- It is presentation tool used to enhance and illustrate your message

Discussion

- PowerPoint's main objective is to augment and illustrate a verbal lecture or talk
- It is presentation tool used to enhance and illustrate your message

Conclusion

- Developed an approach for semantic knowledge representation that supports multimodal reasoning
- Demonstrated how the approach can be used for clinical decision-making
- Defined ensemble reasoning as the integration and interaction of multiple types of reasoning
- Designed, implemented, and integrated various reasoning components to create a semantic workflow for ensemble reasoning based on a clinical reasoning model
- Defined metrics for comparing multiple decision trees
- Designed and organized a study to evaluate clinical relevance or recommendations and rationale
- Compiled and analyzed of the results of the study
- Performed theoretical analyses

Contributions

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Contribution 1

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Contribution 2

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Contribution 3

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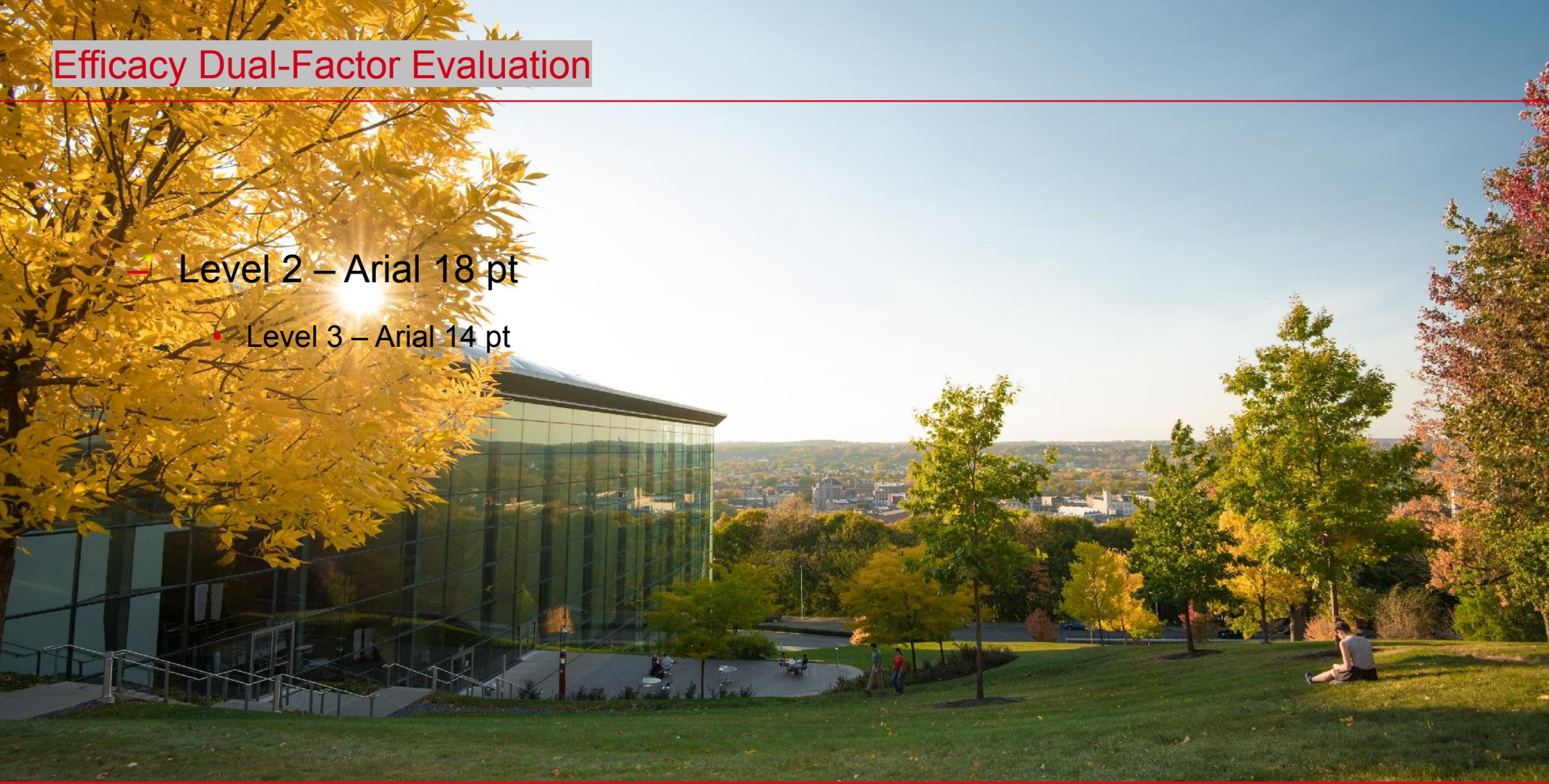
PROPER AND IMPROPER USE OF A POWERPOINT

- You should:
  - Use the template
  - Use font “Arial”
  - Use good-quality images
  - Make punctuation and capitalization consistent
  - Use bullets
  - Include key points and concepts
  - Use diagrams to illustrate complex concepts
- You should not:
  - Use PowerPoint as a handout, putting all spoken words on slides
  - Read your slides or speak to them
  - Use whole sentences or paragraphs on your slides (except for quotes)
  - Use complicated graphics or charts
  - Use flashy transitions and animations
  - Use poor-quality or web-napped images

Single-Factor Evaluation of Treatment Planning

- Level 2 – Arial 18 pt
  - Level 3 – Arial 14 pt

Efficacy Dual-Factor Evaluation

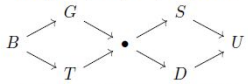
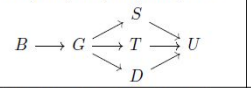
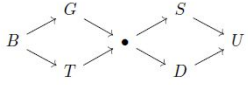
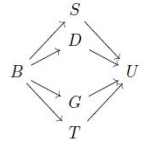
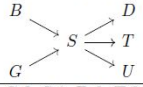
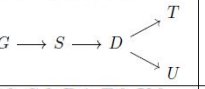
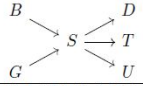
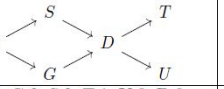
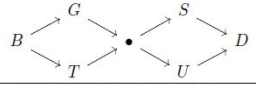
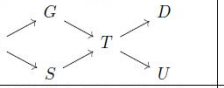
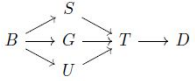
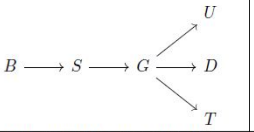
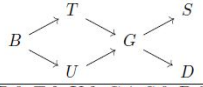
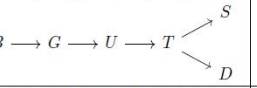
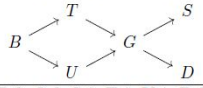
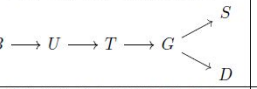
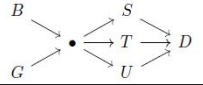
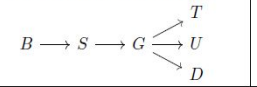


- Level 2 – Arial 18 pt
  - Level 3 – Arial 14 pt

Single-Factor Evaluation of Treatment Planning

Factor	System Ranking	ADA Rankings	M_1	M_2
Efficacy	B:2, G:1, T:1, U:1, S:0, D:0	B:2, G:1, T:0, U:0, S:0, D:0	2	2
Hypoglycemia	B:2, S:1, D:1, G:1, T:1, U:0	B:2, S:1, D:1, G:1, T:1, U:0	0	0
Weight	B:2, S:2, G:2, D:1, T:0, U:0	B:3, S:2, G:2, D:1, T:0, U:0	1	1
ASCVD	B:2, S:1, G:1, T:1, D:0, U:0	B:3, S:2, G:2, T:1, D:0, U:0	3	1
Heart Failure	B:2, S:2, G:1, U:1, D:0, T:0	B:2, S:1, G:0, U:0, D:0, T:0	3	3
Cost	B:2, U:1, T:1, S:0, D:0, G:0	B:3, U:2, T:1, S:0, D:0, G:0	2	1
DKD	B:1, S:1, G:1, D:0, T:0, U:0	B:3, S:2, G:1, D:0, T:0, U:0	2	2

Efficacy Dual-Factor Evaluation

Factors	System Ranking	ADA Rankings	M_1	M_2
Efficacy & Hypoglycemia	B:3, G:2, T:2, S:1, D:1, U:0 	B:3, G:2, T:1, S:1, D:1, U:0 	1	2
Hypoglycemia & Efficacy	B:3, G:2, T:2, S:1, D:1, U:0 	B:2, S:1, D:1, G:1, T:1, U:0 	3	2
Efficacy & Weight	B:2, G:2, S:1, D:0, T:0, U:0 	B:4, G:3, S:2, D:1, T:0, U:0 	4	2
Weight & Efficacy	B:2, G:2, S:1, D:0, T:0, U:0 	B:3, S:2, G:2, D:1, T:0, U:0 	3	2
ASCVD & Efficacy	B:3, G:2, T:2, S:1, U:1, D:0 	B:3, G:2, S:2, T:1, U:0, D:0 	3	3
Heart Failure & Efficacy	B:3, S:2, G:2, U:2, T:1, D:0 	B:3, S:2, G:1, U:0, T:0, D:0 	3	4
Efficacy & Cost	B:3, T:2, U:2, G:1, S:0, D:0 	B:4, G:3, U:2, T:1, S:0, D:0 	3	4
Cost & Efficacy	B:3, T:2, U:2, G:1, S:0, D:0 	B:4, U:3, T:2, G:1, S:0, D:0 	2	1
DKD & Efficacy	B:2, G:2, S:1, T:1, U:1, D:0 	B:3, S:2, G:1, T:0, U:0, D:0 	5	5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